Activity B8

Inquiry Lab

Student Reference 2, 7

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Kinetic Energy and Motion

Before You Start...

In this activity, you will use an elastic to launch an object on a horizontal frictionless surface. When the elastic launches the object, the elastic potential energy of the elastic will be converted to the kinetic energy of the object. This is evident in the speed of the object as it travels across the surface.

The Question

What is the relationship between an object's speed and its kinetic energy?

The Hypothesis

State a hypothesis concerning the speed of an object and its kinetic energy.

Variables

Read over the procedure and identify the type of data you will collect to support your hypothesis. State the manipulated, responding, and controlled variables in your investigation.

Materials and Equipment

air table and accessories
elastic launcher
spark paper
air puck
balance
marking pen
ruler

Procedure

1. Follow the instructions to set up the air table and launcher.
   a) Connect the air source and the spark generator to the air table. Set the spark generator to 10 sparks per second.
   b) Place the carbon paper on the air table. Place the recording paper on top of the carbon paper.
   c) Set up the puck launcher on one edge of the air table so it will launch the puck straight across the table.
   d) On the top of the puck launcher, mark five equal distances for the five different lengths that you will stretch the elastic to launch the puck at different speeds.
   e) Practise launching the puck at these different lengths so that the air puck is launched at ever greater speeds.
2. Create a data table like the one below. Make sure to give your table a title.
3. Using a balance, measure the mass of the air puck. Record this value in kilograms in the data table.
4. Turn on the spark generator and the air source.
5. Pull the air puck against the elastic, stretching the elastic to the first mark. Sharply release the air puck, and observe the spark marks generated on the recording paper. Turn off all the equipment.
6. Slide the recording paper sideways on the air table so that you can take another reading on the same paper.
7. Repeat steps 4 through 6 four more times, stretching the elastic different lengths.

Trial	Mass of the Air Puck m (kg)	Time Interval of the Generated Sparks Δt (s)	Average Distance Travelled During Each Time Interval Δd (m)	Average Speed of the Air Puck v (m/s) Use: $v = \frac{\Delta d}{\Delta t}$	Kinetic Energy of the Air Puck E_k (J) Use: $E_k = \frac{1}{2}mv^2$

8 Remove the recording paper. Label each trail of spark marks as Trial 1, Trial 2, etc.

Analyzing and Interpreting

1. On the recording paper, locate the spark marks generated for Trial 1. Choose four consecutive spark marks near the beginning of the trail. Label these marks as 0, 1, 2, and 3.
2. Carefully measure the distances in metres between marks 0 and 1, 1 and 2, and 2 and 3. Find the average value of the distance travelled, and record this value in the data table.
3. Repeat steps 1 and 2 for the other four trials.
4. Plot a graph of kinetic energy as a function of speed. What does the shape of the graph suggest about the relationship between the speed of an object and its kinetic energy?

Forming Conclusions

5. Was your hypothesis correct? Support your conclusion with results from your graph.

Example Problem B2.5

What is the speed of an 800-kg automobile if it has a kinetic energy of 9.00×10^4 J?

$$E_k = \frac{1}{2}mv^2$$

$$mv^2 = 2E_k$$

$$v^2 = \frac{2E_k}{m}$$

$$v = \sqrt{\frac{2E_k}{m}}$$

$$= \sqrt{\frac{2(9.00 \times 10^4 \text{ J})}{800 \text{ kg}}}$$

$$= \sqrt{\frac{18.0 \times 10^4 \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}}{800 \text{ kg}}}$$

$$= \sqrt{\frac{1.80 \times 10^5 \frac{\cancel{\text{kg}}\cdot\text{m}^2}{\text{s}^2}}{800 \cancel{\text{kg}}}}$$

$$= \sqrt{225 \frac{\text{m}^2}{\text{s}^2}}$$

$$= 15.0 \frac{\text{m}}{\text{s}}$$

The automobile has a speed of 15.0 m/s.

reSEARCH

People have used the kinetic energy of the wind for centuries. Some of these uses include transporting people and goods, grinding grain, pumping water, and drying clothes. Find out how the wind's kinetic energy has been used in various ways. Why is the wind still being used in many places in the world? Begin your search at www.pearsoned.ca/school/science10

Practice Problems

6. A baseball with a mass of 300 g has a kinetic energy of 304 J. Calculate the speed of the baseball.
7. A moving toy with a mass of 7.4 kg has a kinetic energy of 18 J. Calculate the speed of the toy.

B2.3 Check and Reflect

Knowledge

1. What type of energy is associated with the motion of an object?
2. What two factors determine the kinetic energy of an object?
3. Energy is measured in joules, which is a derived unit. State what 1 J is in terms of the fundamental units of measurement. (These units are kilograms (kg), metres (m), and seconds (s).)
4. A mass is attached to a vertical spring and released. It moves through one complete vibration (down and back up).
   a) Discuss the changes in the kinetic energy of the mass from the time that it is released, at the top, to the time that it returns to its starting position.
   b) If energy cannot be created or destroyed, how is it possible for the mass to
      i) gain kinetic energy during part of its vibration?
      ii) lose kinetic energy during part of its vibration?

Applications

5. Determine the kinetic energy of each of the following.
   a) A 0.500-kg ball is thrown horizontally at 12.0 m/s.
   b) A 75.0-kg person is in free-fall and reaches a terminal velocity of 40 m/s.
   c) A 4.00-g bullet is travelling at 140 m/s.
6. A curling rock, sliding down the ice at a speed of 2.40 m/s, is determined to have a kinetic energy of 57.6 J. What is the mass of the curling rock?
7. A 40.0-kg object has an initial kinetic energy of 320 J.
   a) What is the initial speed of the object?
   b) An unbalanced force is applied to accelerate the object to a final kinetic energy of 400 J. What is the change in speed of the object?
8. The kinetic energy of an object was determined while the object's speed was increasing. The data collected were recorded in the table below.
   a) Draw a graph of kinetic energy as a function of the speed.
   b) What does the shape of the graph tell you about the relationship between the speed and the kinetic energy of an object?

Speed v (m/s)	Kinetic Energy E_k (J)
0.0	0.0
1.2	1.4
2.4	5.8
3.6	13.0
4.8	23.0
6.0	36.0

9. The kinetic energy of an object was determined for an object with increasing mass, travelling at a constant speed. The data collected were recorded in the table below.
   a) Draw a graph of kinetic energy as a function of the mass.
   b) What does the shape of the graph tell you about the relationship between the mass and the kinetic energy of an object?

Mass m (kg)	Kinetic Energy E_k (J)
0.00	0.00
1.10	0.55
2.20	1.10
3.30	1.65
4.40	2.20
5.50	2.75

Extension

10. A ball with a mass m travelling at a speed v has a kinetic energy of 40.0 J. Calculate the kinetic energy of the ball if:
    a) the mass is doubled
    b) the speed is doubled

B 2.4 Mechanical Energy

When energy is transferred to an object, it can cause a change in both kinetic and potential energy simultaneously. A ball thrown upward has kinetic energy because of its motion, and also has potential energy because of its position above the surface of Earth. Since kinetic and potential energy are so closely related in many situations involving energy transfers, they are combined as a general type of energy called **mechanical energy**, E_m, which is defined as the energy due to the motion and the position of an object.

Since an object can have both kinetic and potential energy at the same instant, mechanical energy can be calculated using the following formula:

$$\text{mechanical energy} = \text{kinetic energy} + \text{potential energy}$$

$$E_m = E_k + E_p$$

infoBIT

A roller coaster has no engine. It runs on mechanical energy. The conversion of potential energy to kinetic energy and back again drives it as it clatters down and then around the hilly track.

Example Problem B2.6

A 0.300-kg baseball is thrown in a straight line through the air. At a height of 2.50 m above the surface of Earth, it has a speed of 20.0 m/s. What is the total mechanical energy of the baseball?

$$\begin{aligned} E_m &= E_k + E_p \\ &= \frac{1}{2}mv^2 + mgh \\ &= (\tfrac{1}{2})(0.300\text{ kg})(20.0\text{ m/s})^2 + (0.300\text{ kg})(9.81\text{ m/s}^2)(2.50\text{ m}) \\ &= 60.0\text{ J} + 7.36\text{ J} \\ &= 67.4\text{ J} \end{aligned}$$

The kinetic energy of the ball is 60.0 J, the potential energy of the ball is 7.36 J, thus the mechanical energy of the ball is 67.4 J.

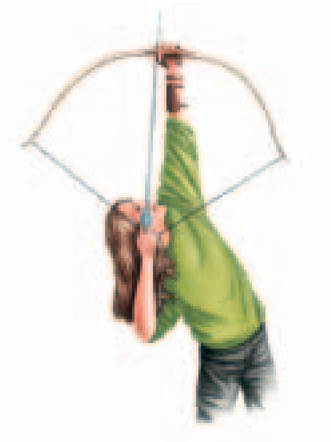


FIGURE B2.12 An archer draws back on the string of the bow to shoot an arrow into the air.

The illustration shown in Figure B2.12 can be used to describe an important concept in physics that involves mechanical energy. When the person pulls the bow string, an average force is being exerted through a distance, and work is being done. This work is stored in the bow as $E_{p(elas)}$. When the string is released, elastic energy is converted into kinetic energy, E_k, as the arrow is released. As the arrow rises into the air, it slows down and loses kinetic energy, but it is rising higher above the surface of Earth, and so gains gravitational potential energy, $E_{p(grav)}$. This illustrates that potential energy can be converted into kinetic energy and kinetic energy into potential energy.

Practice Problems

8. A seagull flying horizontally at 8.00 m/s carries a clam with a mass of 300 g in its beak. Calculate the total mechanical energy of the clam when the seagull is 30.0 m above the ground.
9. A 55.0-kg high-jump athlete leaps into the air in an attempt to clear the bar. At the top of the leap, the athlete has a total mechanical energy of 3.00×10^3 J and is moving at 8.33 m/s. Calculate the gravitational potential energy of the athlete.
10. A construction worker drops a 2.00-kg hammer from a roof. When the hammer is 50.0 m above the ground, it has a total mechanical energy of 1.88×10^3 J. Calculate the kinetic energy of the hammer.

Law of Conservation of Energy

The law of conservation of energy states that the total amount of energy in a given situation remains constant. Energy can be converted from one form to another but the total amount of energy never changes. Thus, the total amount of mechanical energy remains constant. In the absence of outside forces, kinetic energy may be converted to potential energy and vice-versa, without loss, so that the total amount of mechanical energy always remains constant.

$$\text{potential energy} \rightleftharpoons \text{kinetic energy}$$

$$E_p \rightleftharpoons E_k$$

This law is fundamental in situations involving mechanical energy.

Example Problem B2.7

A 1.50-kg rock is dropped over the edge of a cliff, 30.0 m above the surface of a lake. What is the speed of the rock just before it strikes the surface of the lake?

$$\begin{aligned}
E_{p(\text{top})} &= E_{k(\text{bottom})} \\
mgh &= \frac{1}{2}mv^2 \\
mv^2 &= 2\,mgh \\
v^2 &= 2\,gh \\
v &= \sqrt{2\,gh} \\
&= \sqrt{2(9.81\,\frac{\text{m}}{\text{s}^2})(30\text{ m})} \\
&= 24.3\,\frac{\text{m}}{\text{s}}
\end{aligned}$$

The speed of the rock is 24.3 m/s, just before it strikes the surface of the lake.

Practice Problems

11. A 10.0-kg water balloon is dropped from a height of 12.0 m. Calculate the speed of the balloon just before it hits the ground.

12. A 30.0-kg child on a trampoline jumps vertically into the air at an initial speed of 1.60 m/s. Calculate how high the child will rise.

Figure B2.13 shows an example of the conversion and the conservation of mechanical energy. If the masses are released, then the difference in masses causes the larger mass to fall with increasing speed. Because the two masses are attached by a string, the smaller mass will rise with increasing speed. The 2.00-kg mass loses potential energy because it loses height, and it gains kinetic energy because it speeds up during its fall toward Earth's surface. At the same instant, the 1.00-kg mass gains potential energy

because it rises above Earth's surface. It also gains kinetic energy because it is speeding up as it rises. The two masses are connected by a string and so they must move at the same speed. Thus, there are three increases in energy and only one decrease in energy. Is this a contradiction of the law of conservation of mechanical energy? The answer is no. The mechanical energy lost by the 2-kg mass would equal the mechanical energy gained by the 1-kg mass. Energy is always conserved!

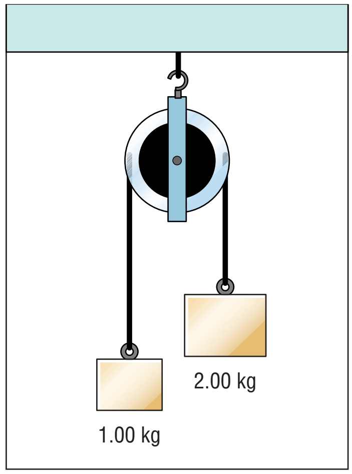


FIGURE B2.13 A pulley with a mass of 1.00 kg hanging on one side and a mass of 2.00 kg hanging on the other is an interesting example of a situation involving conservation of mechanical energy.

Example Problem B2.8

An average force of 100.0 N is required to pull back a bow string a distance of 0.500 m. The bow is aimed vertically.

a) What is the work done on the bow?

b) How much potential energy is stored in the bow?

c) How much kinetic energy does the arrow have at the instant it is released from the bow?

d) What will be the potential energy of the arrow at its highest position in its flight in the air?

a)
$$W = Fd = (100.0\ \text{N})(0.500\ \text{m}) = 50.0\ \text{J}$$

The work done on the bow is 50.0 J.

b)
$$\Delta E_{\text{p(elas)}} = W$$
$$E_{\text{p(elas)}} = 50.0\ \text{J}$$

The amount of elastic potential energy in the bow is 50.0 J.

c)
$$\Delta E_{\text{k}} = E_{\text{p(elas)}}$$
$$E_{\text{k}} = 50.0\ \text{J}$$

When the arrow is released, it has 50.0 J of kinetic energy.

d)
$$\Delta E_{\text{p(grav)}} = E_{\text{k}}$$
$$E_{\text{p(grav)}} = 50.0\ \text{J}$$

As it reaches its highest point, the arrow has its maximum potential energy, 50.0 J.

Practice Problems

13. A 20.0-g dart is fired from a dart gun with a horizontal speed of 4.10 m/s. The total mechanical energy of the dart is 0.481 J. Calculate the gravitational potential energy of the dart.

14. A pendulum consists of a 500-g metal ball suspended on a 50.0-cm string. The ball is pulled horizontally and up a total vertical distance of 10.0 cm. It is then released. At the bottom of the arc, the mechanical energy of the ball was determined to be 0.491 J. What was the speed of the ball at the bottom of its arc?

This example describes the relationship between work and energy and the transformations of kinetic and potential energy. It also illustrates the law of conservation of energy.

Activity B9

Inquiry Lab

Student Reference 5, 6, 7

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Mechanical Energy and the Pendulum

The Question

Is mechanical energy conserved as a pendulum swings?

The Hypothesis

When a pendulum is pulled back to form a 45° angle with the vertical, work is done on the pendulum. This work is stored as potential energy in the pendulum and, when the pendulum is released, the potential energy is converted into kinetic energy. State a hypothesis concerning the law of conservation of mechanical energy in this situation.

Variables

Read over the procedure and identify the type of data you will collect to support your hypothesis. State the manipulated, responding, and controlled variables in this investigation.

Materials and Equipment

- string, 1 m long
- object
- retort stand and clamp
- large blackboard protractor
- metre-stick
- stopwatch
- balance (measuring in grams (g))
- masking tape

Procedure

1. Attach the string to the object.
2. Measure the mass of the object using the balance. Record this value in your notebook.
3. Tie the other end of the string to the clamp on the retort stand.
4. Tape the metre-stick vertically to the retort stand, so that one end of the metre-stick touches the tabletop. Rest the object on the tabletop and adjust the clamp on the retort stand so that the string is taut.
5. Secure the protractor on the clamp at the top of the string so that the string hangs vertically down at the 90° mark on the protractor. Make sure that the string is not touching the surface of the protractor.
6. Slide the base of the retort stand slowly toward the edge of the table so that the pendulum hangs over the side of the table and can swing freely. Secure the base so that the retort stand does not topple over.
7. Pull the pendulum back to the 45° on the protractor.
8. Use the metre-stick to measure the height of the pendulum from the tabletop and record this value in your notebook.
9. Calculate the maximum potential energy of the pendulum using the formula $E_p = mgh$.

Note: Data may be collected using either of the two methods described below. Choose the most appropriate method based on the type of equipment available in your laboratory. Proceed to step 10 or step 14 depending on your equipment.

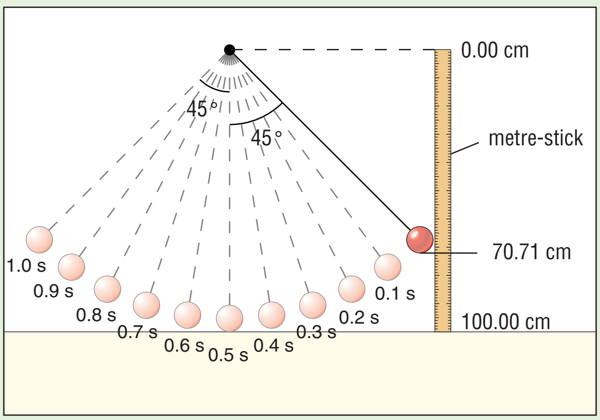


FIGURE B2.14 The positions of the pendulum as it swings through half an arc

Method 1: Using a Motion Sensor and a Computer Interface or a Graphing Calculator

10. Connect the motion sensor to a computer or a graphing calculator. Set the time intervals at 0.10 s and set the distance travelled by the pendulum in metres. Record the data in a table, with time interval as the *x* variable and distance travelled as the *y* variable.
11. Release the pendulum, and allow it to swing to its maximum height on the other side. This is half an arc (Figure B2.14).
12. Stop the pendulum on the other side.
13. Proceed to step 1 of Analyzing and Interpreting.

Method 2: Using Simulated Data

14. If you do not have access to a motion sensor and a computer interface, the measurements have been done for you and are displayed in the table below. Proceed to step 11 of Analyzing and Interpreting.

Time Elapsed as the Pendulum Makes $\frac{1}{2}$ Arc t (s)	Distance Travelled by the Pendulum d (m)	Speed of the Pendulum at Each Time v (m/s)
0.00	0.00	0.00
0.10	0.02	0.48
0.20	0.10	0.96
0.30	0.22	1.44
0.40	0.38	1.92
0.50	0.60	2.40
0.60	0.82	1.92
0.70	0.98	1.44
0.80	1.10	0.96
0.90	1.17	0.48
1.00	1.20	0.00

Analyzing and Interpreting

Method 1. Using a Motion Sensor and a Computer Interface or a Graphing Calculator

1. Complete your data table.
2. Analyze the results of the motion of the pendulum in the data table on your computer. The results should be displayed in a table similar to the one shown here. Make sure your data table has a title.

Time Elapsed as the Pendulum Makes $\frac{1}{2}$ Arc t (s)	Distance Travelled by the Pendulum d (m)

3. Program the computer to display these results on a distance–time graph.
4. What is the shape of your graph?
5. What does the shape of the graph indicate about the motion of the pendulum?
6. Program the computer to display the results as a speed–time graph.
7. What is the maximum speed attained by the pendulum?
8. At what point in the pendulum's swing does it reach this speed?
9. Using the formula $E_k = \frac{1}{2}mv^2$, calculate the maximum kinetic energy of the pendulum when it reaches the bottom of its swing.
10. Compare this value with the maximum potential energy of the pendulum at the top of its arc that you calculated previously.

Method 2: Using Simulated Data

11. Using the simulated results in procedure step 14, draw a distance–time graph.
12. What is the shape of your graph?
13. What does the shape of the graph indicate about the motion of the pendulum?
14. Using the simulated results, draw a speed–time graph.
15. What is the maximum speed reached by the pendulum?
16. At what point in the motion of the pendulum does it reach this speed?
17. Using the formula $E_k = \frac{1}{2}mv^2$, calculate the maximum kinetic energy of the pendulum at the bottom of its swing.
18. Compare this value with the maximum potential energy of the pendulum at the top of its arc that you calculated previously.

Forming Conclusions

19. Based on your calculations, is mechanical energy conserved in the motion of the pendulum? Justify your answer.

reSEARCH

Watch a pendulum for an extended period of time and you will notice that the back and forth motion changes slowly to a circular motion. Using the library or the Internet, research this phenomenon. Why does the pendulum have this circular motion? Is the circular motion clockwise or counterclockwise? How is this motion similar to the circular motion of water going down a drain? Begin your search at www.pearsoned.ca/school/science10

Conversion and Conservation of Energy in a Pendulum

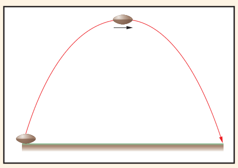
The pendulum is an excellent example of the law of conservation of energy. When the pendulum is initially lifted a certain height above the table, work is done against the opposing force of gravity. The energy expended to do the work is stored in the pendulum as gravitational potential energy. When the pendulum is released and begins its swing, gravitational potential energy is converted into kinetic energy, and the pendulum speeds up. At the midpoint of the arc, the pendulum is moving at its maximum speed, and all the potential energy has been converted into kinetic energy. At this point, the kinetic energy of the pendulum is exactly equal to the initial amount of potential energy. As the pendulum begins to rise toward its maximum position on the other side of its arc, the pendulum slows down, and kinetic energy is converted back to potential energy. At the highest position on the other side, the pendulum stops and has no more kinetic energy. Its potential energy equals the amount of potential energy it had at the beginning because it rises to exactly the same height. Energy is conserved!

B2.4 Check and Reflect

Knowledge

1. What is mechanical energy?

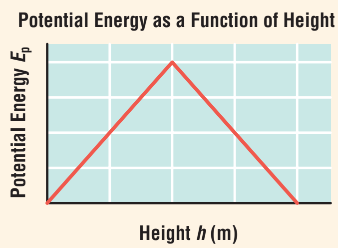
2. A kicker on a football team kicks a football that travels in a trajectory, shown in the diagram:



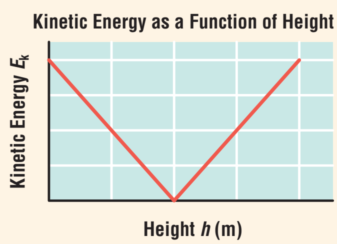
   a) What types of energy does the football have at the moment the ball leaves the kicker's foot?
   b) What types of energy does the football have at a point halfway up to its highest point?
   c) What types of energy does the football have at the highest point of its path?
   d) At what part of its motion are the kinetic and the gravitational potential energy equal?
   e) At what part of its motion is the kinetic energy the least?
   f) At what part of its motion is the gravitational potential energy the least?
   g) Where is the total mechanical energy the greatest? Explain your answer.

3. What is the law of conservation of energy?

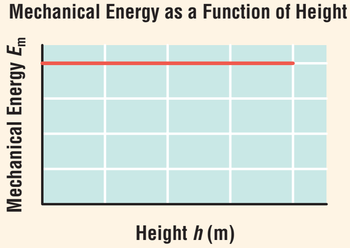
4. A ball is thrown vertically upward from the ground. It rises to a certain height and then falls back to the ground.
   a) Analyze the graph below. What is happening to the potential energy of the ball as a function of its height above the ground?



   b) Analyze the graph below. What is happening to the kinetic energy of the ball as a function of its height above the ground?



c) Analyze the graph below. What is happening to the mechanical energy of the ball as a function of its height above the ground?



Applications

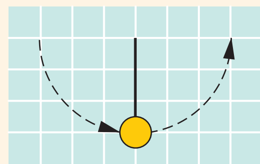
5. An average force of 40.0 N is needed to compress a spring 0.100 m. A 1.00×10^{-2} kg ball is placed on the spring.
   a) Calculate the work done in compressing the spring.
   b) What happens to the work done on the spring?
   c) If the spring is released, what happens to the energy of the spring?
   d) Calculate the energy the ball has at the instant that the ball leaves the spring.
   e) What will be the speed of the ball as it leaves the spring?
   f) If the ball is fired up into the air by the spring, how much gravitational potential energy will the ball gain?
   g) What will be the maximum height that the ball will rise into the air?

6. A 60.0-kg athlete jumps vertically upward from the ground to a height of 0.910 m above the ground. What was the athlete's initial vertical speed?

7. A 0.300-kg billiard ball is propelled from a table at a horizontal speed of 1.50 m/s. If the table is 1.30 m above the floor, what is the mechanical energy of the ball at the instant it leaves the table?

8. A ball is thrown vertically upward from the ground. It rises and then falls back to the ground in a measured time.
   a) Sketch a graph showing gravitational potential energy as a function of time.
   b) Sketch a graph showing kinetic energy as a function of time.
   c) Sketch a graph showing mechanical energy as a function of time.

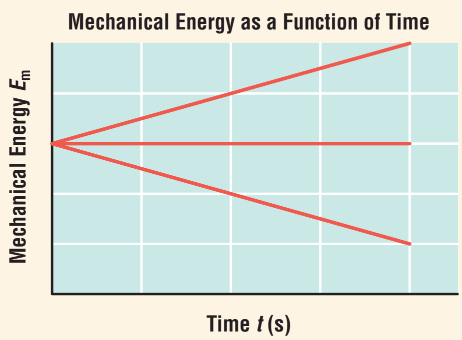
9. A 2.00-kg ball is suspended from a ceiling by a rope 1.50 m long. The ball is pulled sideways and up until the rope is horizontal.
   a) How much gravitational potential energy will be acquired by the ball?
   b) If the ball is then released, what is the maximum speed it acquires?
   c) If the ball swings through its arc to the opposite side, as shown in the diagram, at what position or positions will it have:
      i) maximum gravitational potential energy?
      ii) maximum kinetic energy?
      iii) maximum mechanical energy?



Extensions

10. If a ball at a certain position above the surface of Earth has gravitational potential energy, explain why the ball will not necessarily have the same amount of kinetic energy when it is dropped back down to Earth's surface.

11. Three identical objects are projected horizontally from the same height at the same speeds. The graph below depicts the mechanical energy of each object as a function of time.
    a) Describe what is happening for each object. (Each object is represented by a different line on the graph.)
    b) Which line depicts an impossible situation?



B 2.5 Energy Conversions

info **BIT**

Before metal pots were available, First Nations people used hot stones and non-metal containers to heat water for cooking. They would fill leather bags or pits in the ground with water and then add stones that had been heated in the fire. The heat transferred from the hot stones to the water, raising its temperature.

In your daily life, you constantly encounter energy conversions. When you turn on a light, electricity is converted to light energy. Your body converts the chemical energy in food into the electrical impulses your brain uses to transmit signals. To get the desired type of energy, sometimes several conversions have to happen. Take the example of striking a match. The mechanical energy that moves the match is converted to heat. The heat causes the match to release its stored chemical energy, which is converted to heat and light energy.

Evidence of Energy Conversions

In general, one of several things might happen as a consequence of energy being converted from one form to another.

Motion is the most obvious evidence that an energy conversion has happened. When a pitcher throws a ball, her arm does work, which becomes the ball's kinetic energy.

Climbing stairs is a less obvious evidence of energy. A diver gains gravitational potential energy by climbing the stairs of a diving tower. When he's on the platform, he has raised his position relative to the surface of the water. Whenever something is raised above the surface of Earth, this *change in position* is evidence of gravitational potential energy.

A *change in shape* is also evidence that an object has undergone a change in energy. The drawn bow in Figure B2.15 has gained elastic potential energy as the archer pulls the bow string back, changing its shape. When she releases the bow, it will change its shape again as the elastic potential energy changes to kinetic energy of the released arrow. A stretched elastic band or a pole vaulter's pole mid jump has gained elastic potential energy.

FIGURE B2.15 When the archer has drawn the bow to its maximum position, the bow has gained elastic potential energy through changing its shape.

For a pot of water on the stove, a *change in temperature* is evidence of energy transfer. Energy is being transferred from the hot stove to the cooler pot and water. The pot and water are gaining heat. Heat is the transfer of kinetic energy of the particles in one substance to another; in this case from the element to the pot and water.

Energy Conversions in Natural Systems

The hydrogen–hydrogen nuclear fusion reaction that occurs at the centre of the Sun releases tremendous amounts of solar energy that travels to Earth as electromagnetic waves. When this radiation strikes Earth, it is either absorbed by Earth or reflected back into space. When light energy from the Sun strikes the chlorophyll in plants, a chemical reaction, photosynthesis, occurs that converts carbon dioxide and water into glucose and oxygen. The glucose contains chemical potential energy. When animals eat plants, this chemical potential energy in the glucose is released through the process of respiration in the animals' bodies. Glucose (sugar) from food reacts with oxygen in animal cells to produce carbon dioxide and water. The energy released during respiration, in the form of adenosine triphosphate (ATP), provides the energy necessary for the animal to carry out life functions. It also produces heat.

Millions of years ago, as plants and animals died, they became buried under sediment. As time passed, the layers of dead plants and animals sank deeper into Earth's crust. Through pressure, heat, and other processes, they were transformed into huge deposits of coal, oil, and gas. When these fossil fuels are burned in chemical combustion reactions, they are releasing energy that was trapped millions of years ago.

Minds On... Identifying Energy Conversions in Nature

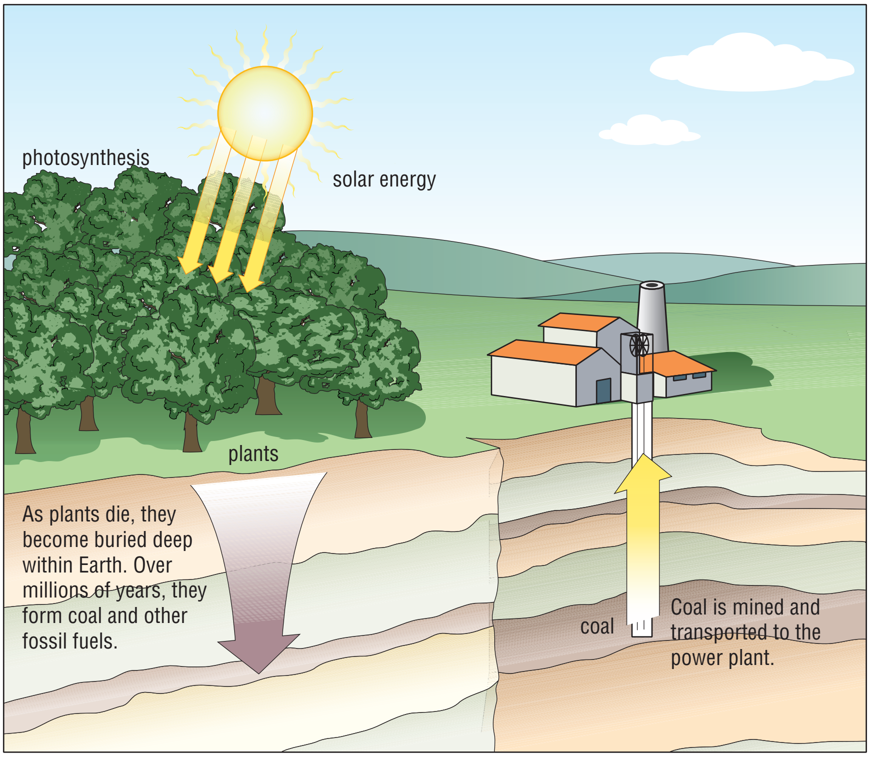


FIGURE B2.16 Energy conversions from the Sun to fossil fuels

In Figures B2.17 and B2.18 on the next page, you will see the energy conversions in hydro-electric and coal-burning power stations. These conversions seem to begin with the dam reservoir and the stockpile of coal, respectively. But the trail of energy conversions really starts at the initial source, the Sun.

Analyze Figure B2.16, depicting the flow of energy from the initial stage of the production of solar energy on the Sun, through to the production of fossil fuels such as coal, oil, and gas. Then answer the following questions.

Questions

1. List all the energy conversions, in order, starting from solar energy being emitted from the Sun to the final use of fossil fuels.
2. Is all the solar energy that strikes plants stored as chemical potential energy in fossil fuels? Can you identify places where solar energy is wasted in this energy conversion system?
3. What is the main difference between photosynthesis and respiration or combustion?

Energy Conversions in Technological Systems

Hydro-electric dams convert the energy of moving water into electricity. This conversion takes many steps. Figure B2.17 shows a cross-section of a hydro-electric power station. The water reservoir behind the dam, A, stores water at a higher level than the generator below the dam, so the water has gravitational potential energy due to its higher position. The water behind the dam is released into the penstock, B. As it flows down the penstock, it loses gravitational potential energy but gains kinetic energy as it increases speed. When the water reaches the turbines, C, its kinetic energy pushes the blades of the turbines. The kinetic energy of the water is converted to the kinetic energy of the turbines. The turbines turn a coil of wire in a magnetic field, D, which converts the turbine's kinetic energy into electrical energy. This electricity is then distributed from the station to users.

A coal-burning power station also uses many energy conversions to generate electricity (Figure B2.18). Coal is placed in the combustion chamber, A, where it burns at a very high temperature. The chemical potential energy in the coal is converted into heat. This heat is then used to change the water in the boiler, B, into steam. The steam is under pressure and is injected into the turbines, C, causing the turbines to rotate. The thermal energy and kinetic energy of the moving steam is converted into kinetic energy as the turbines rotate. The turbines use the kinetic energy to turn a coil of wire in a magnetic field in the generator, D. The kinetic energy is converted into electrical energy.

FIGURE B2.17 A hydro-electric power station converts the gravitational potential energy of water into electrical energy through a series of energy conversions.

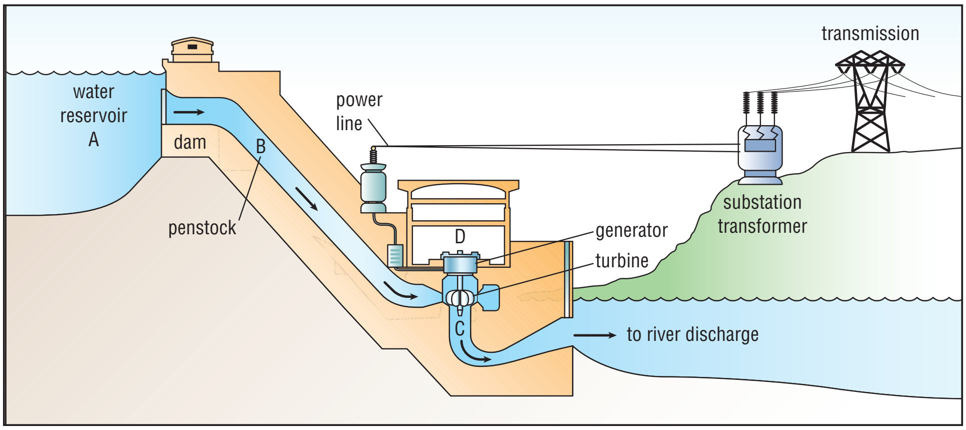
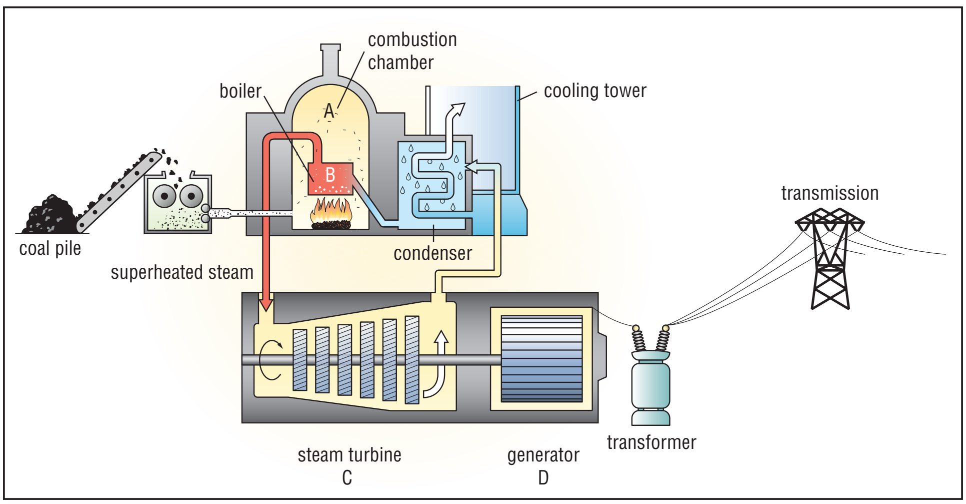


FIGURE B2.18 A coal-burning power station converts the chemical potential energy stored in coal into electrical energy through a series of energy conversions.



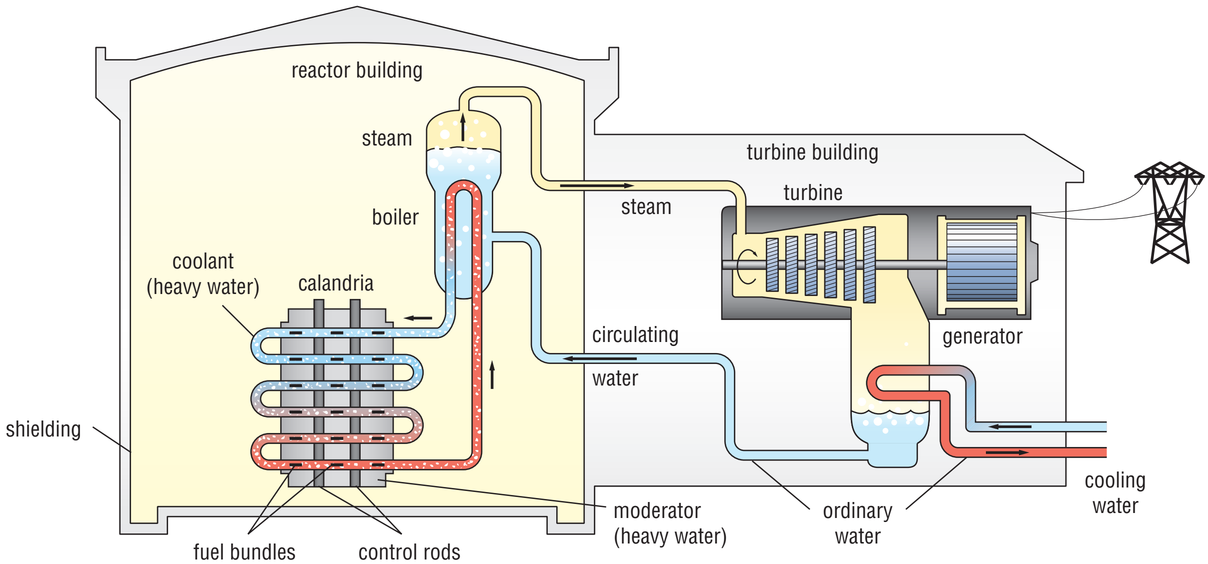


FIGURE B2.19 A schematic diagram of a CANDU nuclear reactor that is used to generate electricity. To rotate the turbines, which generate electricity, steam is heated by nuclear reactions. Instead of a water reservoir or a coal deposit, they require a source of uranium.

Nuclear Energy Conversions

After the Second World War, engineers used the technology of splitting the atom to create a new method of generating electricity. Nuclear power is now used to generate electricity in Canada and around the world.

One of the most widely used nuclear reactors is the Canadian CANDU (CANadian Deuterium Uranium) reactor (Figure B2.19). In the reactor, uranium disintegrates during nuclear fission, releasing nuclear energy as radiation. This radiation is converted to thermal energy, which is used to heat water to steam. Under pressure, the steam is then piped into the turbines and causes them to move. The steam's kinetic energy is converted into the turbines' kinetic energy. The turbines turn a coil of wire in a magnetic field. This converts the turbines' kinetic energy into electrical energy. This sequence of energy conversions is very similar to the conversions in a coal-burning power station. In fact, nuclear power stations and coal-burning power stations are both **thermal power stations**. They create heat to produce steam, which drives the turbines. Power stations powered by natural gas are also thermal power stations.

Solar Energy Conversions

Although the Sun is not really a new source of energy, it is considered new because engineers have only recently developed technologies that efficiently convert sunlight to other forms of energy. One of the most recent and common solar energy conversion technologies is the solar cell.

Solar cells are unlike other technological systems that you've studied so far. They have no moving parts and they convert solar energy directly to electricity. A solar cell is usually composed of two layers of silicon, one with

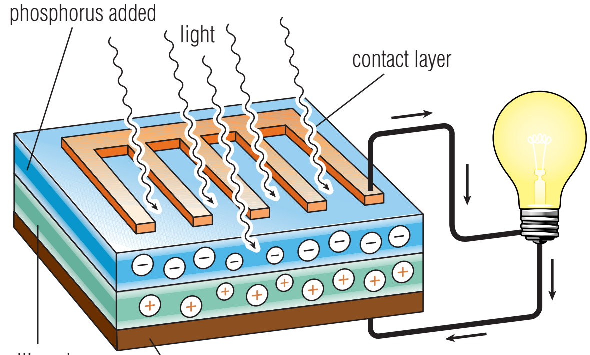


FIGURE B2.20 A cross section of a solar cell illustrates the build-up of charges on the silicon layers.

phosphorus added and one with boron added (Figure B2.20). Normally, electrons are bound up in the silicon crystals in these layers. However, when sunlight hits the silicon layers, it provides energy for some of the electrons to break free of the crystals and move freely. The silicon layer with added phosphorus becomes negatively charged. The second silicon layer with added boron becomes positively charged. The positive and negative layers act in the same way as the positive and negative terminals of a battery, and an electric current flows. The current is then collected by the electrical contact layers shown in Figure B2.20. The electricity can be used directly or stored in a conventional battery for later use.

This energy conversion system can be applied to systems as large as the International Space Station or as small as a solar-powered calculator.

Activity B10

Design a Lab

Student Reference **2, 5, 7, 11**

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Kinetic Energy or Potential Energy?

There are many situations where energy is converted from one form to another. However, the most common type involves mechanical energy, where kinetic and potential energy are interconverted.

The Question

In a situation where potential and kinetic energy are interconverted, will mechanical energy be conserved?

Design and Conduct Your Investigation

1. After considering the above question, write a hypothesis.
2. Decide on the materials and the equipment you will need to test your hypothesis (Figure B2.21).

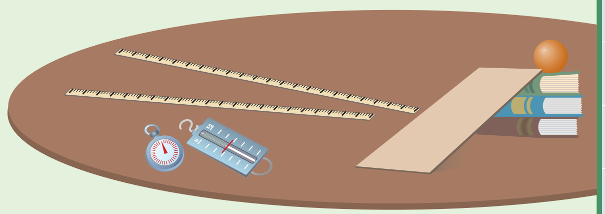


FIGURE B2.21 Possible materials for the investigation

3. Plan your procedure. For example:
   - What variables are you working with? Identify the manipulated, responding, and controlled variables. Predict what results will occur in the responding variable when a change is made in the manipulated variable and give a reason why.
   - How will you vary the manipulated variable to obtain the results you need?
   - What steps do you have to go through to collect the data you need to test your hypothesis?
   - How will you collect the data?
   - How will you record the data?
   - What type of quantitative analysis of your data must be performed to verify your hypothesis?
4. Write up your procedure and show it to your teacher.
5. Carry out the experiment.
6. Compare your results with your hypothesis. Did your results support your hypothesis? If not, what possible reasons might there be for any discrepancy?
7. Compare your experimental design and findings with those of your classmates. How do your results compare with theirs?

Fuel Cells

Like a solar cell, a hydrogen fuel cell operates like a battery. In fact, it's known as the new, improved battery. It converts the chemical energy in a fuel, such as hydrogen, into electrical energy. However, unlike a battery, it does not require recharging. It will produce electrical energy as long as it has fuel. The byproducts of the hydrogen fuel cell are water and heat.

This is why the hydrogen fuel cell is so popular in spacecraft. Not only can the fuel cell supply the necessary electricity to maintain all the electrical instruments on board the spacecraft, but it can also supply all the heat and water necessary for the trip, from the "waste" products of the cell's reaction.

reSEARCH

Fuel cells are now being used to power vehicles. Use the Internet and other resources to find out how fuel cells work. Draw and label a diagram of a fuel cell to show how it operates. Begin your search at www.pearsoned.ca/school/science10

B2.5 Check and Reflect

Knowledge

1. List all the energy conversions that occur in a hydro-electric power station.
2. List all the energy conversions that occur in a coal-burning power station.
3. a) What single energy conversion in a hydro-electric station produces the most waste heat?
   b) What single energy conversion in a thermal coal-burning power station produces the most waste heat?
4. Explain why more energy is wasted in a coal-burning power station than in a hydro-electric power station.
5. One method to show energy conversions is to use concept maps. Map the conversion of energy in a nuclear reactor, from the initial form of nuclear energy to the final form of electrical energy.
6. Explain how solar cells are similar to batteries.

Applications

7. List all the energy conversions you can see in your classroom. State the initial form of energy and the resulting form of energy.
8. Trace the chain of energy transformations from the Sun to the final form of energy, in each of the following:
   a) A heating pad is plugged into an electrical outlet.
   b) A lawn mower is idling.
   c) A horse is pulling a cart.
9. Give an example to justify each of the following statements:
   a) Energy comes in many forms.
   b) Energy can be stored for a long time.
   c) Energy can be changed from one form to another.
10. A weightlifter holds a barbell above his head and drops it. What evidence is there that an energy conversion has taken place?

Extension

11. In what ways could heat be regarded as mechanical energy?

UNIT B 2.0

Section Review

Knowledge

1. List seven different types of energy.

2. What is the current definition of energy?

3. Define the term “thermodynamics.”

4. What was one principle of thermodynamics that was developed during the study of the nature of heat?

5. What is the difference between nuclear fusion and nuclear fission?

6. What type of nuclear reaction is occurring in the Sun?

7. What is the difference between kinetic energy and potential energy?

8. Describe an example where an object has:
a) only kinetic energy
b) only gravitational potential energy
c) kinetic and potential energy

9. When does potential energy become “useful” energy?

10. What term is common to kinetic and potential energy?

11. Explain the difference between the mass and the weight of an object.

12. Why is chemical energy considered a form of potential energy?

13. A person leaps high up into the air. At what point in the upward motion does the person have:
a) maximum kinetic energy?
b) minimum kinetic energy?
c) maximum gravitational potential energy?
d) minimum gravitational potential energy?
e) kinetic energy equal to gravitational potential energy?

14. Give an example of mechanical energy being converted to:
a) thermal energy
b) sound
c) light
d) electricity

15. What are the byproducts of a hydrogen fuel cell?

Applications

16. Scientists who observed a demonstration of Newton’s cradle in 1666 could not explain one of their observations. What was this observation? How did scientists later in the 1600s try to explain it?

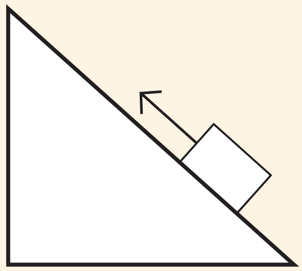
17. How did Young unite the terms “work” and “mechanical energy”?

18. Describe an example where each of the following forms of energy can be found in a technology:
a) chemical
b) light
c) thermal
d) radiant
e) electric
f) kinetic
g) sound

19. Describe a natural system in which the following forms of energy can be found:
a) chemical
b) light
c) thermal
d) radiant
e) electric
f) kinetic
g) sound

Section Review

20. The inclined plane shown below has a vertical distance of 1.00 m and the length along the incline is 1.50 m. A force of 30.0 N, applied to the string parallel to the incline, slides a 1.00-kg block of wood a distance of 1.50 m up the incline.



Calculate the work done by the force in moving the block of wood up the incline to the top.

21. Determine the gravitational potential energy of the block of wood at the top of the incline.

22. Explain why the work done in question 20 is not equal to the energy gained by the object in question 21.

23. A 50-kg gymnast leaps on a springboard and rises vertically to a height where the gravitational potential energy of the gymnast is 800 J. Calculate the elastic potential energy stored in the springboard when the gymnast first leaped on the springboard.

24. State the assumption you had to make to answer question 23.

25. Calculate the initial vertical speed of the gymnast at the moment the feet of the gymnast left the springboard in question 23.

26. State the assumption you had to make to answer question 25.

27. Describe a process involving your body in which there is a transformation of at least three different types of energy.

28. Describe a process where there is a transformation of the following forms of energy:

a) chemical to light

b) light to chemical

c) kinetic to heat

d) heat to kinetic

e) electric to magnetic

f) magnetic to electric

29. Why are solar cells used in providing the electrical energy for space stations?

30. An ice cube is placed at the top of an inclined plane. Eventually, a coating of water begins to appear between the ice cube and the inclined plane. Slowly, the ice cube begins to slide down the inclined plane. Identify the evidence that energy is involved in each of these observations.

Extensions

31. Design an experiment to investigate the conversion of kinetic energy into potential energy. In your design, state a problem, identify the manipulated and the responding variables, make a hypothesis that describes the relationship between the two variables, and suggest a procedure that could be used to take the desired measurements.

32. Discuss all the ways that the energy of a drop of water in a cloud is different from the energy of a drop of water in the surface of a calm lake.

33. Does Earth have mechanical energy as it travels in its orbit around the Sun? Explain your answer.

34. Discuss the different approaches of a scientist and an environmentalist in arguing the importance of the development of a hydrogen fuel cell automobile for the future.

35. Which source of energy do you think should be further developed for the future? Justify your answer.

UNIT B

3.0

Principles of energy conservation and thermodynamics can be used to describe the efficiency of energy transformations.

Key Concepts

In this section, you will learn about the following key concepts:

- technological innovations of engines that led to the development of the concept of energy
- design and function of technological systems and devices involving potential and kinetic energy, and thermal energy conversions
- efficient use of energy, and environmental impact of inefficient use of energy

Learning Outcomes

When you have completed this section, you will be able to:

- describe how the first and second laws of thermodynamics have changed our understanding of energy conversions
- describe qualitatively, and in terms of thermodynamic laws, energy transformations in devices and systems
- define, operationally, "useful" energy from a technological perspective, and analyze the stages of "useful" energy transformations in technological systems
- recognize that there are limits to the amount of "useful" energy that can be derived from the conversion of potential energy to other forms in a technological device
- identify the processes of trial and error that led to the invention of the engine, and relate the principles of thermodynamics to the development of more efficient engine designs
- explain, quantitatively, efficiency as a measure of the "useful" work compared to the total energy put into an energy conversion process or device
- apply concepts related to efficiency of thermal energy conversion to analyze the design of a thermal device
- compare the energy content of fuels used in thermal power plants in Alberta (costs, benefits, efficiency, sustainability)
- explain the need for efficient energy conversions to protect our environment and to make judicious use of natural resources

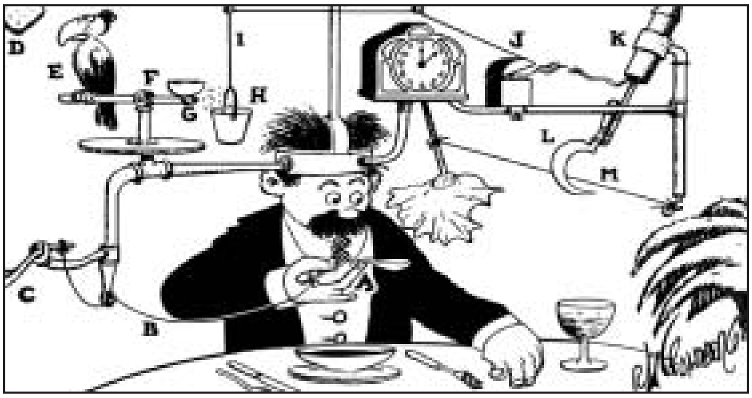


FIGURE B3.1 This drawing shows a humorous attempt at designing the perfect machine.

Rube Goldberg, a cartoonist during the 1920s, poked fun at the gadgets that were being designed to supposedly make people's lives easier. His "inventions" were drawn only for amusement, but surprisingly, they could actually work. One of his inventions, an automatic napkin, is shown in Figure B3.1. It uses a complicated set of machines to accomplish a very simple task: wiping the diner's moustache.

Rube Goldberg's drawing is humorous because we know intuitively that the machine is extremely inefficient. One swipe of the diner's hand could eliminate the nine or so automatic steps. In fact, Rube Goldberg machines have come to symbolize inefficient machines: they exert a lot of effort to produce small results. In the real world, engineers do the opposite of Rube Goldberg. They design efficient machines that exert the minimum possible effort to produce largest possible results.

At the start of the Industrial Revolution, engineers developed machines to do work, and as time passed, they tried to make these machines do work more efficiently. As scientists looked at these attempts to increase efficiency, they developed some principles about how heat behaves.

In this section, you will learn about the laws that govern heat. You will also learn how the development of technologies during the Industrial Revolution led to advances in the scientific concept of energy and how these technologies were improved and refined over time. You will study the efficiency of energy conversions in machines. Finally, you will investigate how thermal energy conversions affect our environment.

B 3.1 Laws of Thermodynamics

All machines in daily life are governed by physical laws. These laws describe the relationships between work and energy transformations. However, they focus on one type of energy transfer: heat. The previous sections showed how energy transformations or transfers resulted in changes in motion or position of an object. This section will deal with changes in temperature that are also a result of work and energy transformations or transfers.

infoBIT

Although the automobile engine is one of the most popular heat engines used, up to 33% of the energy supplied to the automobile is lost as heat.

Systems

For investigations into work done and energy transfers, it is necessary to set boundaries for the objects involved. These boundaries define the system. A **system** is a set of interconnected parts. In studies of work and energy transfers, the system is the object or objects involved in the transfers. Everything else is considered the surroundings or the environment. For example, in a gasoline-powered lawn mower, the system could be the engine. The surroundings could be the other parts of the mower, the ground, and the air around the mower. The set boundaries are arbitrary, and you can change them. In the lawn mower example, the system could have been the entire lawn mower. The surroundings would then be the ground and the air.

After you define a system and its surroundings, you should state the type of system you are studying.

- An **open system** is one that exchanges both matter and energy with its surroundings. For example, suppose Earth is a system and the universe is its surroundings. Earth is an open system, since it can exchange both energy and matter with its surroundings.
- A **closed system** is one that cannot exchange matter but can exchange energy with its surroundings. For example, a closed can of soup is a closed system because matter cannot move into or out of it, but energy can move into the can.
- An **isolated system** is one that cannot exchange either matter or energy with its surroundings.

FIGURE B3.2 (a) Heat flows from the fire to the metal rod.

(b) The person does work on the spring of the pogo stick.

The First Law of Thermodynamics and the Law of Conservation of Energy

It is important to distinguish heat from work. Work involves the movement of matter from one location to another, whereas heat is a transfer of thermal energy from one location to another. Both heat and work can affect systems.

The energy of a system can be increased in two ways. Either heat can be added to a system from the surroundings (Figure B3.2(a)), or work can be done on a system by its surroundings (Figure B3.2(b)). Work done on the system by the surroundings is considered positive work because the energy of the system increases.

Similarly, the energy of a system can decrease in two ways. Either heat

FIGURE B3.3 (a) Heat flows from the hot metal rod to the water.

(b) The spring of the pogo stick does work on the person.

can flow out of a system to its surroundings (Figure B3.3(a)), or work can be done by a system on its surroundings (Figure B3.3(b)). Work done by a system on its surroundings is considered negative work because the energy of the system will decrease.

In the previous section, you were introduced to the law of conservation of energy as it relates to mechanical systems. The law of conservation of energy can be stated in more general terms: Energy cannot be created or destroyed. It can only be transformed from one form to another, and the total amount of energy never changes. The **first law of thermodynamics** is really just a restatement of the law of conservation of energy, except one of the forms of energy involved is heat. This law states that the total energy, including heat, in a system and its surroundings remains constant. Whenever heat is added to a system, it transforms into an equal amount of some other form of energy. This law is supported by Joule's experiments, outlined in section B2.1.

When heat is added to a system, some of the energy goes into increasing the internal energy of the system. This increases the temperature. Some of the energy is used to move parts or to do work on the system. This increases the mechanical energy.

$$\text{heat added to the system} = \text{mechanical energy} + \text{heat}$$

This is what happens in most real-world situations. Most machines involve many moving parts that are in contact with one another. These parts rub together and this friction produces heat. Even though some energy is lost as heat, the law of conservation of energy or the first law of thermodynamics still applies: The amount of heat put into a system must equal the amount of mechanical energy plus heat lost by the system. Theoretically, the system could gain the same amount of mechanical energy as the heat input energy. But in reality, the mechanical energy gained never comes close to the theoretical maximum because most of the input energy is lost from the system as heat.

Activity B11

Inquiry Lab

Student Reference 5, 7, 11

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Bouncing Balls

The Question

Which type of ball most closely resembles a perfect machine?

The Hypothesis

A perfect machine transfers all of its energy into the same or another form of energy completely, with no energy lost to the surroundings as heat or other forms of energy. Study the balls in the materials, and state a hypothesis about which of the given balls would do the best job of converting one form of energy into another. In your hypothesis, state how you would determine if the bouncing ball resembles a perfect machine.

Variables

Identify the manipulated, responding, and controlled variables in the experiment.

Materials and Equipment

3 different types of balls (basketball, golf ball, lacrosse ball, super ball, etc.)

metre-stick

balance (measuring in grams(g))

Procedure

1. Create a data table in your notebook like the one below. Make sure your table has a title.
2. Put the ball on the balance. Record its mass in the appropriate column of your table.
3. Set the metre-stick in a vertical position with the "0" reading at the bottom.
4. Drop a ball from the top of the metre-stick to the floor, and carefully note the height to which the ball bounces. Repeat this procedure three or four times and record each value in your notebook. Use these values to calculate the average value for the return height. Record the value in the appropriate column in the table.
5. Repeat steps 2 to 4 for the other balls.

Analyzing and Interpreting

1. List the energy conversions from the moment you lift the ball to the top of the metre-stick, to the time that the ball reaches its highest point on its bounce.
2. Explain how the conversion of energy for each ball illustrates the first law of thermodynamics.
3. What happened to the lost energy? Is the lost energy a violation of the law of conservation of energy?

Forming Conclusions

4. According to your data, which ball best resembles a perfect machine? Justify your answer.
5. Which ball least resembles a perfect machine? Justify your answer.
6. Do the results of the experiment agree with your hypothesis?

Type of Ball	Mass of the Ball m (kg)	Starting Height h (m)	Starting Potential Energy $E_p = mgh$ (J)	Average Return Height h (m)	Ending Potential Energy $E_p = mgh$ (J)	Loss of Potential Energy ΔE_p (J)
		1.00				

The Perfect Machine Cannot Be Achieved

Ideally, once energy is added to start a machine, the machine should convert all this input energy directly into mechanical energy output, without any energy loss. Since all the input energy is converted completely into mechanical energy, the amount of mechanical energy produced by the machine should equal the amount of energy put into the machine. If no energy is converted to other forms of energy, then the machine should continue to operate indefinitely. These types of machines are called **perfect machines** or **perpetual motion machines**. Although they come close, those shown in Figure B3.4 are not perfect or perpetual motion machines. It is impossible to create a truly perfect machine.

In order for a machine to be classified as a perfect or perpetual motion machine, all the mechanical energy in the system must be completely conserved as mechanical energy during any transformations. In the activity with the bouncing balls, when a ball is lifted into the air, it has mechanical energy in the form of gravitational potential energy. When the ball is dropped, the potential energy is converted into kinetic energy. When the ball hits the floor, the ball bounces upward converting kinetic energy into gravitational potential energy. If no energy is lost to the surroundings, then the ball should rise to exactly the same height. The ball that bounces highest most resembles a perpetual motion machine. In the experiment, no balls will rebound to the same height as the previous bounce because some of the energy is converted to heat, sound, and deformation in each collision with the floor.

The Second Law of Thermodynamics

If you place a hot-water bottle in your bed, the bed will warm up and the hot-water bottle will slowly cool down. Eventually, the bottle and the bed will reach the same temperature. The heat transfers from the bottle to the bed, so the total amount of energy in the bottle and bed remains constant. This is consistent with the first law of thermodynamics, but it also illustrates the **second law of thermodynamics**, which describes the direction of energy flow in natural processes. The second law states that heat always flows naturally from a hot object to a cold object, but never naturally from a cold object to a hot object.

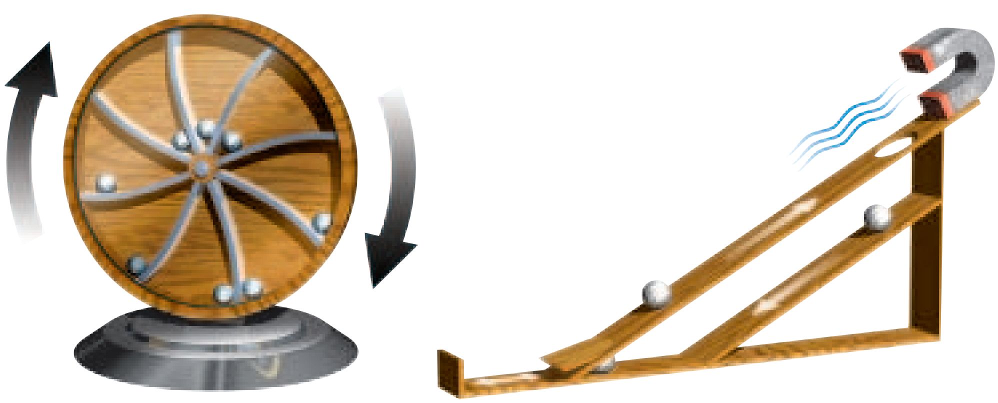


FIGURE B3.4 Attempts at perpetual motion machines

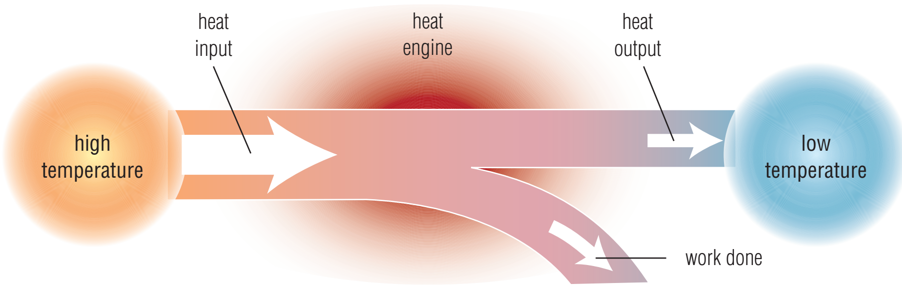


FIGURE B3.5 When heat in a heat engine flows from a higher temperature to a lower temperature, only part of this energy is transformed into work output. The rest is expelled as waste heat.

When the heat in a **heat engine** flows from a high-temperature area to a low-temperature area, this heat can be converted into mechanical energy, which can do work. A heat engine is a device that converts heat into mechanical energy. However, only some of the input heat can be converted to mechanical energy output. The remaining heat is expelled as exhaust heat (Figure B3.5).

For example, in an internal combustion engine, the fuel in the combustion chamber burns at a high temperature, causing the piston to move and gain mechanical energy. The remaining energy is expelled as heat through the exhaust. The exhaust heat has a lower temperature than the input heat.

The hypothetical temperature-difference boat shown in Figure B3.6 is an application of the second law. One pipe leads to the surface of the ocean, which is warmer. The other pipe leads to the deep ocean, which is cooler. Heat flows from hot to cold, so as the heat from the warm-water tank flows to the cool-water tank, it turns a turbine, which turns the propeller. The cold water flows out through the pipe deep in the ocean. Hypothetically, the boat should move because the water is flowing from hot to cold and does work in the process.

According to the second law of thermodynamics, heat never flows naturally from cold to hot. However, heat can be made to move from cold to hot. You have to do work to make this happen.

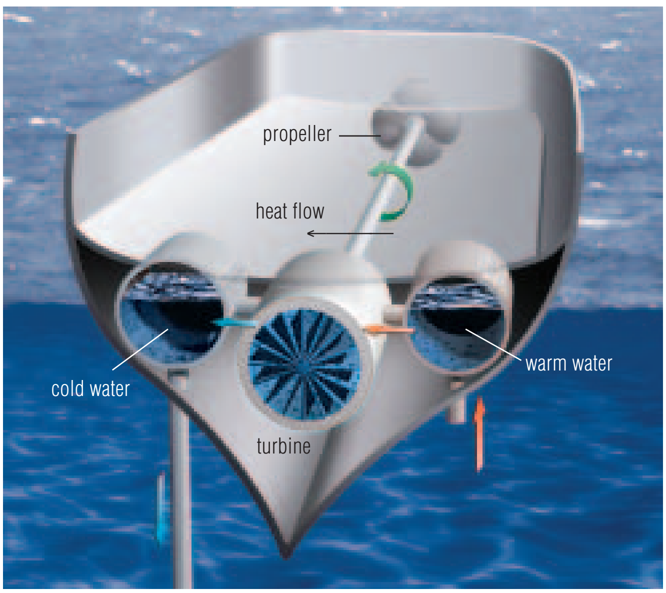


FIGURE B3.6 A hypothetical temperature-difference boat

Heat Engines and Heat Pumps

The study of the interrelationships between heat, work, and energy is called thermodynamics, from the Greek word *therme,* meaning "heat." It began less than 200 years ago out of efforts to produce heat engines (Figure B3.7(a)), which are devices that convert heat into mechanical energy, and **heat pumps** (Figure B3.7(b)), which are devices that use mechanical energy to transfer heat.

Heat engines and heat pumps are similar in that they both operate on the principle that heat flows naturally from a hot substance to a colder one and, in the process, can be made to do work. However, there is an important difference between them.

*re*SEARCH

Since heat naturally flows from hot to cold, all hot objects are transferring thermal energy and cooling off. Eventually, all objects will be at the same temperature and the thermal energy-transfer process will stop. Using the library or the Internet, research how this concept will result in the heat death of the universe. Write a brief summary of your findings. Begin your search at www.pearsoned.ca/school/science10

(a) The jet engine is an example of a heat engine.

(b) The air conditioner is an example of a heat pump.

FIGURE B3.7 Examples of a heat engine and a heat pump

Heat Engines

A thermo-electric converter, shown in Figure B3.8, is an excellent example of a heat engine that follows the second law of thermodynamics. One end of the converter is inserted in water at a temperature of 10°C and the other end is in water at a temperature of 90°C. Heat flows naturally from a hot substance to a cooler one, as stated in the second law of thermodynamics. As this heat, which is thermal energy, flows through the metal junction connecting the two sides, the thermal energy is converted to electric energy, which runs the electric motor. The electric motor, in turn, converts the electric energy into mechanical energy causing the fan to rotate. The device has used a temperature difference to convert heat into mechanical energy. Friction in the electric motor limits the amount of heat that is converted to mechanical energy. The steam engine is another example of a heat engine. You will learn more about steam engines in section B3.2.

FIGURE B3.8 A thermo-electric converter is an example of a heat engine.

Heat Pumps

A refrigerator pumps heat from inside the cooler interior space to warmer air outside the refrigerator. This process is not natural, and so work must be done by the refrigerator (Figure B3.9). To accomplish this, the refrigerator uses electric energy to pump a refrigerant through copper piping, which is an excellent heat conductor. The refrigerant has a very low boiling point and changes from a liquid to a gas at about −40°C. The process begins at the compressor. Here, the refrigerant emerges as a cool liquid under low pressure. As it is pumped through the copper piping, it absorbs heat from the interior and so the interior cools. As the refrigerant absorbs heat, its temperature rises above −40°C. It then vaporizes into a gas and flows into a compressor, where the gas is compressed causing its temperature and pressure to rise. When this happens, the gas gives off thermal energy. This thermal energy is transferred to the air surrounding the refrigerator. The refrigerant is then pumped into a condenser, where it is cooled and liquefied. The cycle then repeats.

FIGURE B3.9 A refrigerator is a heat pump. Heat has to be pumped from inside the refrigerator to outside the refrigerator.

B3.1 Check and Reflect

Knowledge

1. Define the term "thermodynamics."
2. State the first law of thermodynamics.
3. What is the distinction between work and heat?
4. Identify whether each of the following is best explained by the first or second law of thermodynamics.
   a) A bouncing ball eventually comes to rest on the floor.
   b) A metal spoon eventually becomes hot when placed in a pot of boiling water.
   c) Energy cannot be created or destroyed.
5. What is the difference between a heat engine and a heat pump? Give an example of each.
6. What is a perpetual motion machine?
7. State the second law of thermodynamics.

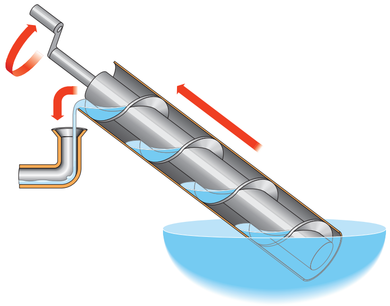
Applications

8. If two sticks are rubbed together and ignite, is the work being done on the sticks positive or negative work?
9. Water is observed to condense on the outside of a cold glass. Which way is heat flowing?
10. Which law of thermodynamics best describes the following statements? Explain your answer.
    a) You can't get something for nothing.
    b) You can't even get close.
    c) A rock will never suddenly jump into the air.

Extensions

11. Is it possible to cool a room down on a hot day by leaving the refrigerator door open? Justify your answer using the laws of thermodynamics.
12. What is the difference between a perpetual motion machine and a Rube Goldberg machine?

B 3.2 The Development of Engine Technology



(a) The Archimedes screw

(b) The Persian wheel

FIGURE B3.10 These simple turbines were used to pump water. They could be turned by animals, moving water, or wind.

Early scientists and engineers realized the importance of inventing machines for making heavy tasks easier to do. However, their machines were limited to simple mechanisms, such as the lever, pulley, wheel and axle, and the screw. Initially, the sources of energy to operate these machines were humans or animals. Later, wind and flowing water were also used. All early machines used sources of energy that people could see or touch. People had not yet discovered that there were "hidden" sources of energy, so the concept of energy was unknown.

The first machine to use a "hidden" source of energy was Hero's steam engine, shown on page 124. But his machine was only a novelty device and did nothing useful, so no one studied it seriously at the time. People did not recognize heat as a useful source of energy for machines.

For most of recorded history there were humans and animals to do all the necessary tasks, and humans used wood to fuel their fires. There was no need to invent sophisticated machines. But things changed in the 1600s. By then, practically all the trees in England had been cut down. So people switched to using coal. Because the demand for coal grew and grew, deeper mines were dug to extract it.

One of the major problems in coal mining was pumping water from deep mines. At first, miners used existing pump systems to pump out the water. These systems (Figure B3.10) had limitations. The Archimedes screw and the Persian wheel, which are turbines, could not lift the water very far because of the downward force of the water. The water held in a large Archimedes screw or Persian wheel was simply too heavy to lift. In a reciprocating pump (Figure B3.11),

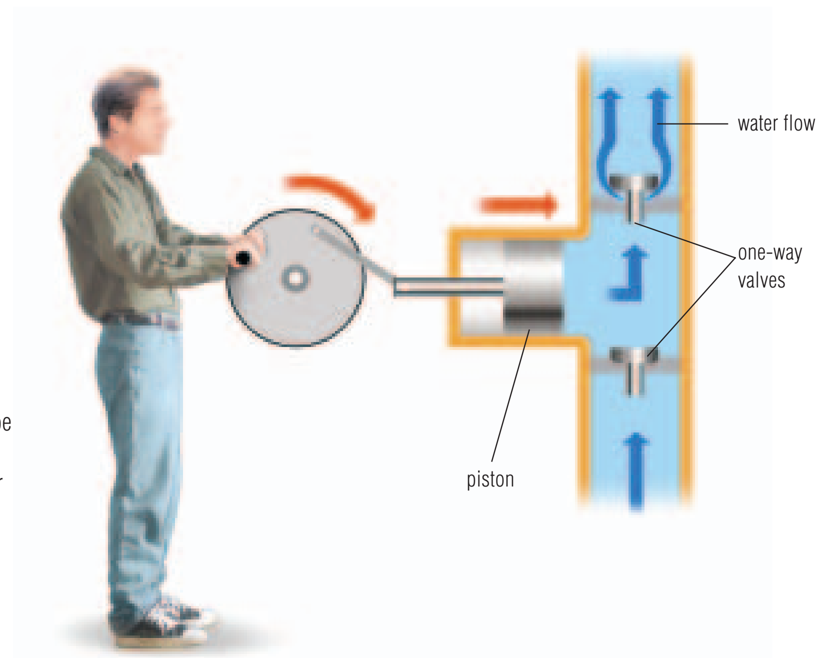


FIGURE B3.11 A simplified version of a reciprocating pump, which uses a piston moving back and forth in a pipe to drive water upward. As the piston is pulled outward, it creates a vacuum, and atmospheric pressure pushes water into the cylinder through the one-way intake valve. When the piston is pushed inward, water is pushed upward through the one-way outtake valve.

atmospheric pressure can only push water up to a height of 9 m. So the reciprocating pump was also limited in the height it could raise water. Miners needed a more powerful machine that could be operated continuously, with an engine that used some other, more powerful source of energy to drive the pump.

Developing a Technology

Technology does not suddenly appear out of nowhere. Developing a technology involves a step-by-step process. The process usually starts with some understanding of scientific concepts. Inventors and engineers use these concepts to create a technology. This new technology usually has flaws or drawbacks, and others try to improve it. As they try to improve it, their knowledge of the science grows. They use this increased knowledge and new scientific discoveries to improve the technology. Today's internal combustion engine followed this process. It began with the gunpowder engine, as described in detail below. Figure B3.15 summarizes the process in a time line.

The Gunpowder Engine

The Science In 1680, Christian Huygens, a Dutch mathematician and physicist, recognized that a successful reciprocating pump needs a force to drive the piston forward and a force to pull it back. Could a piston be driven forward using an internal source of energy?

The Technology Huygens experimented with a gunpowder engine, in which gases generated by an explosion inside the engine drove a piston forward into a cylinder.

The Drawbacks This engine was not developed because of the obvious hazards of explosions and because there was no powerful internal mechanism to pull the piston back so that the engine could operate continuously.

The Heat Engine

The Science Breakthroughs in the development of an engine came with two scientific discoveries. In 1654, Otto von Guericke, a German physicist, demonstrated the tremendous forces of vacuums. He fitted two hollow hemispheres together and created a vacuum inside by extracting the air through a valve. Two teams of eight horses pulling in opposite directions could not pull the hemispheres apart. The other discovery was that water increases its volume by 1300 times when heated to form steam.

The Technology Using these discoveries, French scientist Denis Papin designed the first heat engine in 1690 (Figure B3.12). This device would use heat to create steam to do work.

The Drawbacks Papin did not pursue the development of his engine because he had difficulty making the large drum in which the water was to be heated.

*info***BIT**

The first powered road vehicle was built in France in 1769 and had a steam-powered engine. It was called the Cugnot road locomotive.

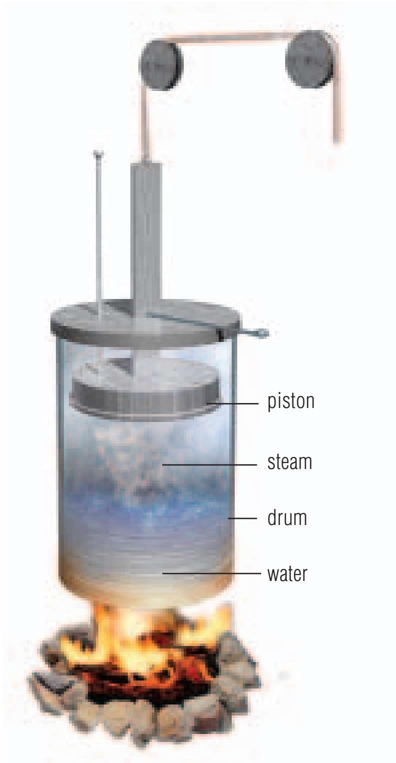


FIGURE B3.12 Illustration of the first steam-powered engine, developed by Papin

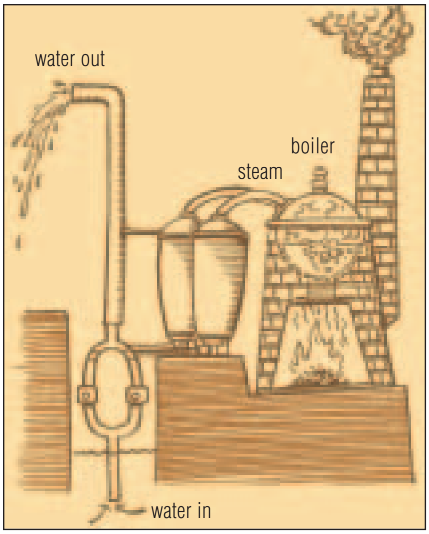
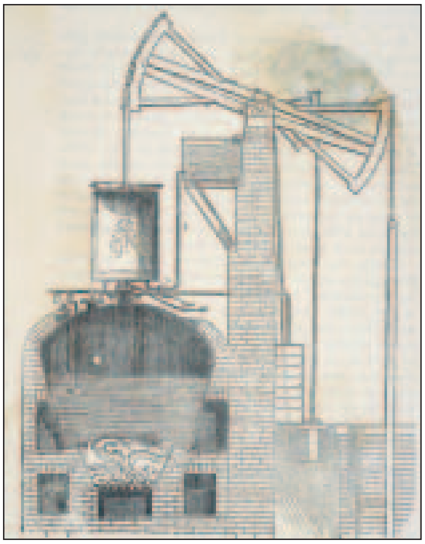


FIGURE B3.13 An illustration of the Savery engine in a mine



The Savery Engine

The Technology In England, in 1698, Thomas Savery invented the first successful steam-powered pump (Figure B3.13), which was used to pump water out of mines.

The Drawbacks This pump could lift water to a height of only 6 m and so it wasn't much of an improvement over animal-powered pumps. To lift to higher distances, the steam would have to be under higher pressure. But the boiler could not produce that amount of pressure without exploding.

The Newcomen Engine

The Technology Patented in 1712 by Thomas Newcomen, the next heat engine also used steam as the driving force (Figure B3.14). A boiler produced steam that forced the piston up a cylinder. When cold water was sprayed on the outside of the cylinder, the steam would condense and the piston would move back down the cylinder. The piston rod was connected to a pivoting beam, which in turn was connected to the mine pump. The up-and-down motion of the piston drove the pump.

The Drawbacks This steam engine was easy to build and maintain and could pump water to higher distances. However, the cycle of heating and cooling the cylinder was very inefficient, and the engine required tremendous amounts of heat to function.

FIGURE B3.14 The Newcomen engine was also called the beam engine. A pivoting beam connected the piston on the left to the mine pump on the right.

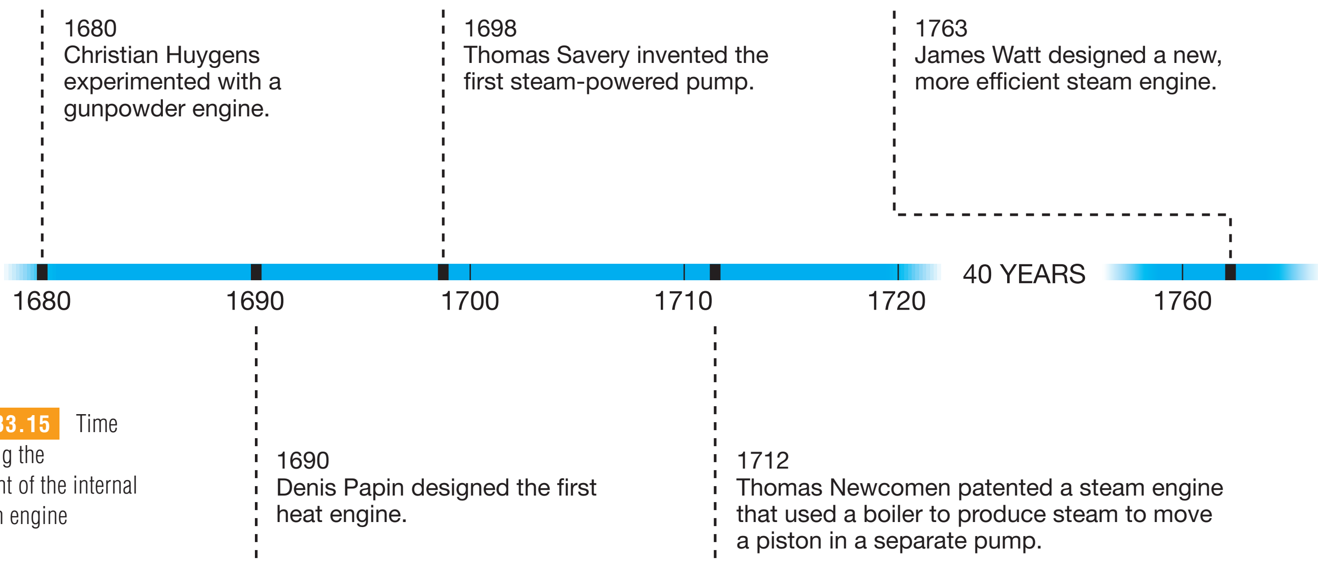


FIGURE B3.15 Time line showing the development of the internal combustion engine

The Watt Engine

The Technology In 1763, a Scottish instrument maker named James Watt was asked to repair a Newcomen engine. He was shocked by its poor performance. He realized that there was a tremendous waste of heat when water was heated and cooled in the same cylinder. Watt designed a new, more efficient steam engine that had a separate condenser to cool the steam so that the boiler cylinder always remained hot. This reduced the amount of heat required to operate the steam engine, making it over three times more efficient than Newcomen's engine. For over 100 years, the Watt steam engine dominated the market. During this period, there were many improvements in the design of the steam engine (Figure B3.16). Steam engines weren't just used to drive water pumps. They also drove the huge machinery in mills, as well as in trains and ships.

The Drawbacks Although steam engines were relatively easy to build and maintain, they were very large. They needed big boilers to create the steam that was piped to parts of the machine that did the work. Because of this, steam engines could not be made small enough to replace horse-drawn carriages. They were also hot, dirty, and very inefficient at converting heat to useful energy. Most of the heat they created was lost to the surroundings. The time was right for a change in engine technology.

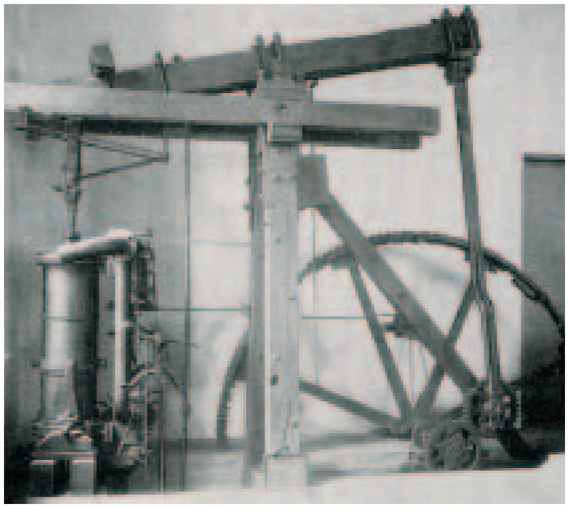
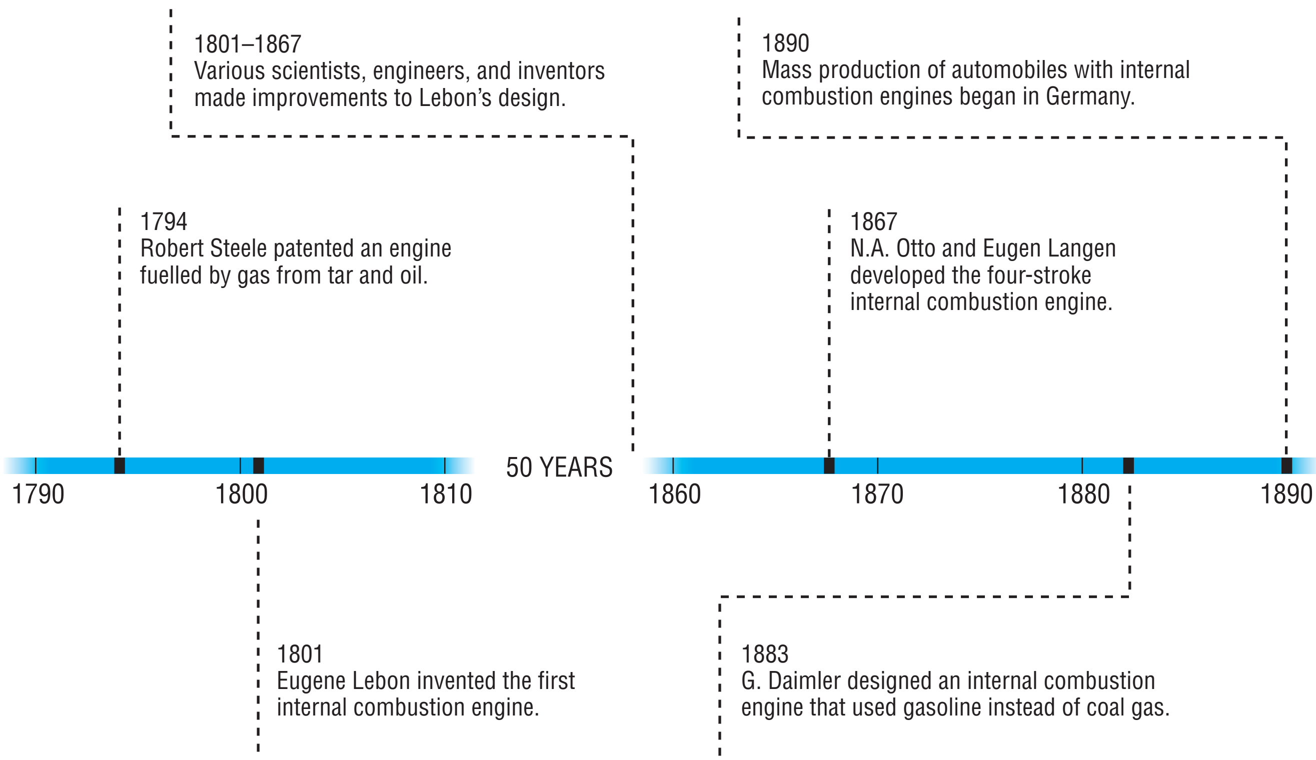


FIGURE B3.16 In this later model of a Watt engine, piston rods were connected to a flywheel, which allowed the engine to be used to drive different types of machinery.

infoBIT

To help finance his work on the steam engine, James Watt surveyed canals and designed bridges.



The Internal Combustion Engine

THE SCIENCE In 1794, Robert Steele looked for another source of energy to replace steam. He revived Huygen's idea of using the gas produced from explosions and lodged a patent for a piston engine fuelled by gas from tar and oil, ignited by a flame.

THE TECHNOLOGY Seven years later, in 1801, Philippe Lebon invented an engine that improved on Steele's design. It used coal gas ignited by an electrical spark. This was an **internal combustion engine**, meaning energy was released by burning fuel, ignited by an electrical spark, inside the engine. (This ignition method is used in modern vehicle engines through spark plugs.)

THE DRAWBACKS This engine was still very inefficient and could not produce sufficient force necessary to operate a machine.

THE TECHNOLOGY In 1867, in Germany, N.A. Otto and Eugen Langen improved the efficiency of the engine by compressing the coal gas–air mixture before ignition. Under pressure, the explosion of the mixture produces more force. They developed the four-stroke internal combustion engine, which is still used in many modern automobile engines (Figure B3.17). The four-stroke internal combustion engine works by moving a piston up a cylinder, compressing the gas–air mixture. The firing of the spark plug ignites the gas–air mixture, creating high temperature and pressure in the cylinder. The high pressure moves the piston down the cylinder. The movement of the piston turns the crankshaft, which turns the wheels.

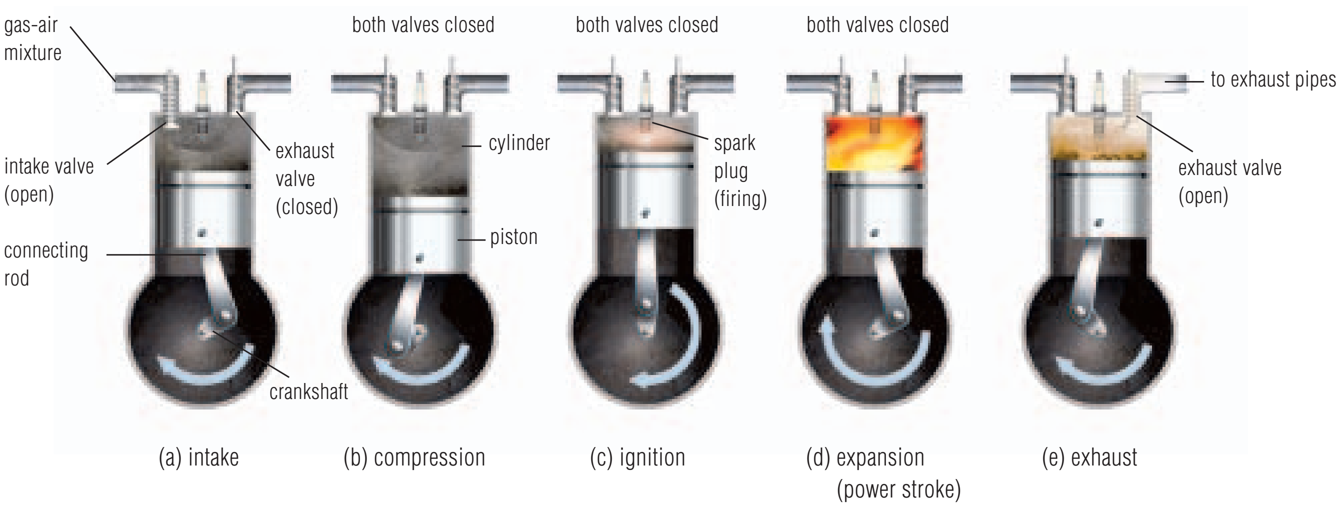


FIGURE B3.17 Fuel and exhaust gases are moved in and out of an internal combustion engine by opening and closing valves.

Almost every engine in the early 1900s was an Otto engine and it could produce the same amount of power as a horse, or 1 hp (horsepower).

The Drawbacks The Otto engine used coal gas as a fuel, which doesn't burn very hot, and so the engine was not very powerful.

The Technology The most important innovation in the internal combustion engine came in the 1880s, again in Germany, after Gottlieb Daimler designed a petroleum-fuelled internal combustion engine that used gasoline instead of coal gas. Petroleum burns much hotter than coal gas. This engine was small enough to power road vehicles. The technology of the engine had evolved to become practical, and mass production of these engines for use in automobiles began (Figure B3.18).

info BIT

One horsepower (hp) was a measure of the amount of power generated by a horse that could lift a 4500-kg mass a distance of 1 m in 60 s. This historical measure for the power of an engine was determined by James Watt as he watched horses working in the coal mines. 1 hp (horsepower) = 746 W (watts)

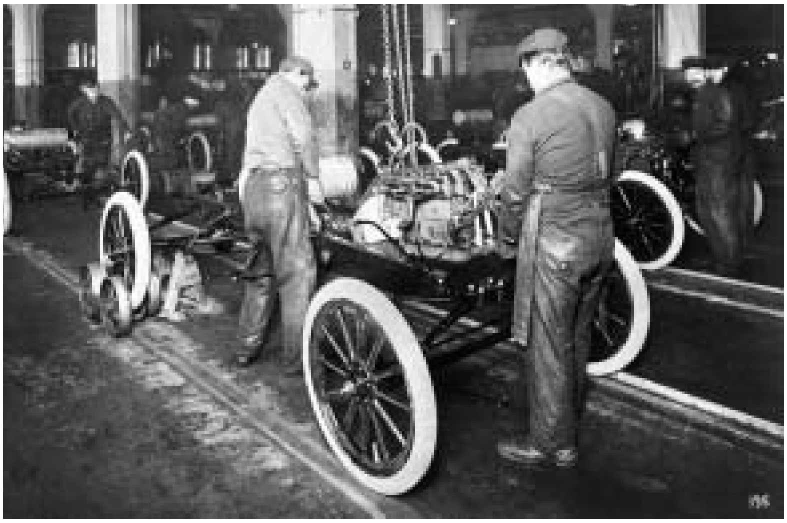


FIGURE B3.18 Mass production of cars with internal combustion engines

Minds On... Motors and Engines Today

Motors and engines are devices that convert energy into some form of motion. For example, the motor in an electric fan causes the fan blades to turn. Engines and motors have become so much a part of our lives that it is difficult to imagine life without some of them.

Part A

- Identify up to 10 different types of devices that use engines to operate. These devices may be in machines, appliances, games, or gadgets in and around your home.
- For each device, identify its energy source (electrical outlets, batteries, gasoline, solar cells, etc.). For each device, decide if you could not possibly, could possibly, or could definitely live without it.
- Summarize your results in a table.

1. What type of engine or motor was the most commonly found in devices at home?
2. What was the most common source of energy?
3. Were you surprised at the devices you could not live without? or those that you could live without?

Part B

- In groups of two or three, brainstorm the uses of effective engines in industrialized societies such as Canada. Research examples from your list or additional examples and explain how these engines have a central role in our society. Write a summary report relating the importance of effective engines to modern industrialized societies.

Activity B12

Problem-Solving Investigation

Student Reference 3, 7

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Using Steam to Power Boats

Recognize a Need

Early engineers harnessed the power of steam to drive mining equipment. But steam can also be used to propel vehicles, including boats. In this investigation, you will create a model boat that is powered by a chemical combustion reaction. A burning candle boils water, causing steam to be produced, which propels the boat.

The Problem

How do you build a boat that uses a burning candle as its energy source?

Materials and Equipment

1 piece of Styrofoam, 10 cm × 15 cm, 2 cm thick
1 piece of Styrofoam, 10 cm × 10 cm, 2 cm thick
1 piece of Styrofoam, 10 cm × 8 cm, 2 cm thick
aluminium foil
water
rubber or cork stopper with hole to fit medicine dropper or glass tubing
medicine dropper or glass tubing
test tube
2 laboratory candles, 2 cm in length
box cutter
matches
glue
metre-stick
stopwatch
lab sink or small aquarium
modelling clay

Criteria for Success

- Build a steamboat. Use the materials and the basic design listed below.
- Test your boat. It must travel in a straight line on the water for approximately 15 cm.
- Alter the basic design to improve the performance of the boat.
- Analyze the alterations you made and communicate how they affected the boat's performance.

Build a Prototype

CAUTION: Be careful when handling the box cutter.

1. Use the 10 cm × 15 cm piece of Styrofoam as the bottom of your boat. Glue the 10 cm × 10 cm piece of Styrofoam to one end of the bottom of the boat, as shown in Figure B3.19. This is the back of your boat.
2. Glue the 10 cm × 8 cm piece of Styrofoam near the front of the boat to act as a support for the test tube, as shown.
3. Cover the top of the boat's bottom with the aluminium foil.
4. Carefully insert the medicine dropper or glass tubing through the hole in the rubber or cork stopper.
5. Fill the test tube about half-full of water. Insert the stopper with tubing into the test tube.
6. Using the box cutter, make a hole in the back of the boat for the medicine dropper or glass tubing, as shown. With the dropper or tubing through the hole, position the test tube so it is resting at a slight angle on the front support.
7. Glue the two candles to the foil on the bottom of the boat near the bottom of the test tube, as shown.
8. Place the metre-stick along the length of a sink or a tank in your lab.

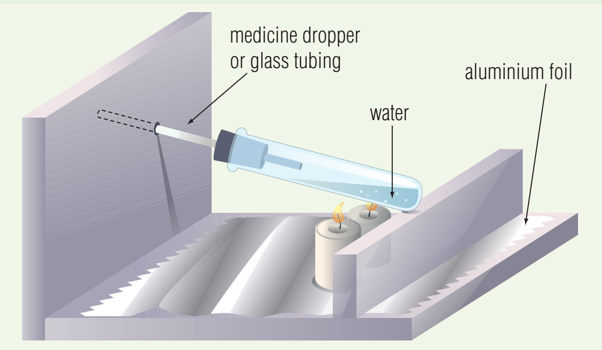


FIGURE B3.19 Steam-powered boat

Test and Evaluate

9. Place the boat in water and mark the starting position of the boat.
10. Light the candles with matches.
11. Measure the time it takes to travel 15 cm or to come to a stop, whichever comes first.
12. Record your boat's initial time in your notebook.
13. Note whether your boat moves at all or whether it moves in circles.
14. Consider aspects of the engine design that could affect the propulsion of the steamboat and make a list of these aspects.

Modification Made to the Steamboat	Trial #	Time Taken for the Steamboat to Travel 15 cm (s)
	1	
	2	

15. Modify one aspect of the design and do two trials of this modification.
16. Create a table in your notebook like the one shown and record data from your design alterations. Make sure your data table has a title.
17. Decide how you will evaluate whether a modification improved the boat's performance.

Communicate

1. Study your results and list the modifications that affected the propulsion of the steamboat.
2. State how each modification affected the propulsion of the steamboat.
3. How successful was your design in producing the necessary energy to propel the steamboat?

Developing Future Technologies

You have learned how, in the development of engine technology, the concept of energy and the laws of thermodynamics were discovered. Thus, developing a technology can lead to new scientific concepts.

Likewise, new technologies can be developed based on existing scientific laws and concepts. Spacecraft engineers have already predicted that using solar winds (discovered in the early 1950s) will be more efficient than using rocket fuel in propelling a human-operated space vessel across the vast expanse of space to Mars. They have designed spacecraft with wind sails, based on the concepts of wind energy and interplanetary magnetic field theory.

Science-fiction writers often dream up amazing futuristic systems and machines. When these are brought to "life," through special effects, on a television or movie screen, the possibilities do not seem far-fetched at all. Could a machine ever be able to replicate food and beverages out of "thin air," simply from a voice command to do so? Would it really be possible for living objects to be "beamed" or transported from one point in space to another, reappearing intact and fully functional on the other side? What type of energy would be required for such technological systems?

For now, many of these imaginative machines remain just that—part of the imagination—either because the pure science behind such technologies is not known to us yet, or because the science is simply not possible at all. But there is no doubt that in the research to develop a new technology, new aspects of the science behind the technology are being unravelled all the time.

reSEARCH

Using the Internet or the library, research the manufacture of some of the largest steam engines.

- Which ship had the larger steam engine: the *Titanic* or the *Queen Mary*?
- What locomotive had the largest steam engine and what railway company used it?

Begin your search at www.pearsoned.ca/school/science10

Recently, scientists have been able to "transport" a photon of light from one point of space to another. This is still very far off from the transportation of an atom, let alone a living cell! But, in using concepts developed in the theoretically-based science of quantum physics, the researchers have revealed yet again that *anything* is possible. Indeed, the development of future technologies is limited only by the limits of our existing scientific and technological knowledge.

B3.2 Check and Reflect

Knowledge

1. Explain why Hero's steam engine was used only for entertainment purposes.
2. What events in the 1600s led to the invention of technologies that used steam energy?
3. What two scientific discoveries in the 1600s led inventors to use steam to drive an engine?
4. Why was the steam engine developed before internal combustion engines that used coal gas or gasoline?
5. Why did Watt consider the Newcomen steam engine highly inefficient?
6. What was one change that Watt made to the design of the steam engine to make it more efficient?
7. List two advantages and two disadvantages of the steam engine.
8. What innovation did Daimler introduce to the internal combustion engine and why was it an improvement?
9. In the internal combustion four-stroke engine, what is the purpose of the intake valve and the exhaust valve?

Applications

10. Identify the major innovation in the design of the steam engine introduced by the following inventors. Describe how each innovation improved on the design.
    a) Papin
    b) Newcomen
    c) Watt
11. Draw a simplified diagram of a reciprocating piston. Describe the process that draws water into the cylinder through the intake valve and the process that forces water through the outtake valve.
12. Why was the internal combustion engine rather than the steam engine chosen to propel road vehicles?

Extensions

13. Research each of the following vehicles or machines and state whether the engine, in most cases, employs a reciprocating piston or a turbine.
    a) a minivan
    b) a 747 airplane
    c) a small propeller airplane
    d) a small propeller boat
    e) a lawn mower
    f) a motorcycle
14. Identify three appliances or machines in your home that use:
    a) a piston engine
    b) a turbine

B 3.3 Useful Energy and Efficiency

After machines had been developed to harness energy transformations to do work, the focus shifted to how efficiently these machines could do the work. When James Watt was asked to repair a Newcomen engine, he saw how poorly the engine performed. He was the first engineer to examine the efficiency of machines.

If machines or engines are to produce mechanical energy, then they must have moving parts. These moving parts rub against each other and produce friction, which in turn produces heat. For example, when two sticks are rubbed together, the heat generated can ignite them. While the person wants to produce heat with the sticks, heat from friction is unwanted in most machines.

Engineers try to reduce the amount of friction between moving parts to reduce waste heat. Magnetic technology is allowing for some near-zero-friction situations. It does this by minimizing contact between the moving parts. The infoBIT at the beginning of section B1.1 describes how MAGLEV trains in Japan are designed to overcome friction by eliminating wheels and tracks. High-powered magnets force the train to rise (levitate) above a guideway and move forward. This technology allows the trains to achieve higher speeds than conventional trains.

*info***BIT**

The table below shows the energy consumed by the various components in an automobile from the combustion of gasoline.

Component in the Automobile	Energy Consumed (%)
exhaust system	33
cooling and heating system	33
drive train	10
accessories	4
internal friction	6
useful energy that propels the automobile forward	14

Useful Energy

The purpose of a machine is to convert the initial energy added to it into the type of energy needed to do the work that you want done. All other types of energy produced and work done are considered wasted energy or work. The initial energy source is called **energy input**. The desired energy needed to do the work is called **useful energy output**, and the work the machine is supposed to do is the **useful work output**.

For example, the purpose of a light bulb is to provide light by converting electric input energy to light output energy. However, a light bulb also produces heat in the process. The light is the useful energy output and the heat is the wasted energy (Figure B3.20).

Systems with moving parts always lose some energy as heat, which is consistent with the first and second laws of thermodynamics. In the first law, the energy that is supplied to a system must equal all the energy that is gained by the system. For example, the energy supplied to your body (the system) by food energy must equal the energy of all the useful work done, plus all the wasted energy, which includes heat and the mechanical energy of the moving parts of your body. According to the second law, heat flows from hot to cold and, in the process, it can be made to do work. However, during the thermal energy transfer, some energy is always lost to the surroundings. Thus the efficiency of a system can never be 100%. This means that you can never come close to getting the energy out of a system that you put into it.

FIGURE B3.20 A light bulb produces more heat than useful light energy.

Efficiency

Efficiency is a measurement of how effectively a machine converts energy input into useful energy output. It is expressed as a ratio:

$$\text{efficiency} = \frac{\text{useful work output}}{\text{total work input}}$$

If efficiency is expressed as a percent, then the term is called the percent efficiency of a machine. Since there are different types of energy conversion devices, there are several formulas to calculate their percent efficiencies. Table B3.1 shows the efficiencies of some common engines.

TABLE B3.1 Efficiencies of Some Common Engines

Type of Machine or Engine	Efficiency (%)
automobile internal combustion engine	12–15
electric engine	Up to 95
steam reciprocal engine	50–75
steam turbine engine	Up to 40

FIGURE B3.21 The mechanical efficiency of a crane is much less than 100%.

1. Conversion of Total Mechanical Energy to Useful Mechanical Energy

Some machines or systems involve the conversion of mechanical energy to another form of mechanical energy. For example, a crane uses mechanical energy to do the work of lifting a load vertically to the top of a building (Figure B3.21). The load gains mechanical energy in the form of gravitational potential energy. The mechanical energy efficiency can be calculated as shown below.

$$\text{percent efficiency} = \frac{\text{useful mechanical energy or work output}}{\text{total mechanical energy or work input}} \times 100\%$$

$$= \frac{E_{\text{m(useful output)}}}{E_{\text{m(total input)}}} \times 100\% \quad \text{OR} \quad = \frac{W_{\text{useful output}}}{W_{\text{total input}}} \times 100\%$$

Example Problem B3.1

A crane lifts a load of construction materials from the ground to the second floor of a building. In the process, the crane does 2.30×10^4 J of work or mechanical energy input, while doing 8.00×10^3 J of useful work or mechanical energy output in lifting the load. What is the mechanical percent efficiency of the crane?

$$\text{percent efficiency} = \frac{E_{\text{m(useful output)}}}{E_{\text{m(total input)}}} \times 100\%$$

$$= \frac{8.00 \times 10^3 \text{ J}}{2.30 \times 10^4 \text{ J}} \times 100\%$$

$$= 34.8\%$$

The crane is 34.8% efficient.

Practice Problem

1. In lifting a car, the total mechanical energy input of a hydraulic hoist is 5.61×10^4 J, while the useful mechanical energy output is 1.96×10^4 J. Calculate the percent efficiency of the hoist.

Example Problem B3.2

An internal combustion engine with an efficiency of 15.0% is used to do 3.20×10^4 J of useful work, or mechanical energy output. Calculate the mechanical energy input that had to be supplied by the combustion of fuel in the engine.

$$\text{percent efficiency} = \frac{E_{\text{m(useful output)}}}{E_{\text{m(total input)}}} \times 100\%$$

$$15.0 = \frac{3.20 \times 10^4 \text{ J}}{E_{\text{m(total input)}}} \times 100\%$$

$$15.0 = \frac{(3.20 \times 10^4 \text{ J})(100\%)}{E_{\text{m(total input)}}}$$

$$E_{\text{m(total input)}} = \frac{(3.20 \times 10^4 \text{ J})(100\%)}{15.0}$$

$$= 2.13 \times 10^5 \text{ J}$$

The mechanical energy input was 2.13×10^5 J or 213 kJ.

Practice Problem

2. A small electric motor has an efficiency of 85%. In lifting a small load, it produces 15 J of mechanical energy input. Calculate the useful mechanical energy output of the motor.

2. Transfer of Total Thermal Energy to Useful Thermal Energy

If a pot of water is sitting on a hot stove element, the heat from the element will be transferred to the pot and the water. The efficiency of heat transfer in a system may be determined using the following formula.

$$\text{percent efficiency} = \frac{\text{heat}_{\text{useful output}}}{\text{heat}_{\text{total input}}} \times 100\%$$

Example Problem B3.3

In heating a pot of water, 2.00×10^3 J of heat was supplied by the stove element. If only 5.00×10^2 J of heat was actually gained by the water (heat output), what was the percent efficiency of the stove element?

$$\text{percent efficiency} = \frac{\text{heat}_{\text{useful output}}}{\text{heat}_{\text{total input}}} \times 100\%$$

$$= \frac{5.00 \times 10^2 \text{ J}}{2.00 \times 10^3 \text{ J}} \times 100\%$$

$$= 25.0\%$$

The stove element has an efficiency of 25.0%.

Practice Problem

3. A Bunsen burner supplies 4.00×10^3 J of heat to a small beaker of water. Only 125 J of heat is actually gained by the beaker and water. Calculate the percent efficiency of the burner.

Activity B13

Inquiry Lab

Student Reference **1, 2, 5**

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Efficiency of a Thermal Device
(Teacher Demonstration)

Before You Start...

Your teacher will do all the steps in this activity that involve handling the lead shot. Make sure to record the data carefully.

The Question

What is the relationship between the mechanical energy and heat in an energy conversion device?

The Hypothesis

Read over the procedure and state a hypothesis concerning the relationship between changes in the device's mechanical energy and its heat output.

Materials and Equipment

clear plastic tube with a 2.5-cm diameter, 1 m long
2 cork or rubber stoppers
1500 g of lead shot or pellets
thermometer or temperature probe
5 medium-sized Styrofoam cups
electronic balance or triple beam balance
metre-stick

Procedure

1. Create a data table like the one below. Be sure to give it a title.

CAUTION: Lead is poisonous. Use gloves when handling lead shot, and wash your hands thoroughly when you have finished.

2. Label the five cups as 1, 2, 3, 4, and 5, respectively.
3. Place the first Styrofoam cup on the balance. Measure the mass of the empty cup in grams.
4. Slowly add about 300 g of lead shot into the Styrofoam cup.
5. Carefully measure the mass of lead shot and the cup and then calculate the mass of the lead shot. Record this value in the appropriate column of your data table.
6. Using a thermometer or a temperature probe, determine the initial temperature of the lead shot to the nearest 0.1°C.
7. Place a stopper into one end of the hollow tube and carefully pour the lead shot into the tube. Place the other stopper into the open end.
8. Hold the tube upright and use the metre-stick to measure the distance, to the nearest 0.01 m, between the top of the lead shot in the tube and the stopper at the top. This distance is the average height the lead shot will fall in the next step. Record this value in your data table.
9. Hold the tube in a vertical position, keeping the stoppers firmly in place with both hands. Quickly flip the tube 180° and stop the tube in a vertical position, allowing all the lead shot to drop the entire length of the tube to the bottom. Continue flipping the tube in this manner 7 more times for a total of 8 flips.

Styrofoam Cup	Mass of Lead Shot m (g)	Initial Temperature $t_{initial}$ (°C)	Final Temperature t_{final} (°C)	Average Height the Lead Shot Falls h (m)	Number of Times the Tube Was Flipped
1					8
2					16

10. Remove the bottom stopper and let out the lead shot into the Styrofoam cup and measure the final temperature of the shot. Record this value in the appropriate column in your data table.

11. Repeat steps 3 to 10 using Styrofoam cups 2, 3, 4, and 5 and fresh lead shot at room temperature, but flipping the tube 16, 24, 32, and 40 times, respectively.

Analyzing and Interpreting

1. Complete a table in your notebook similar to the one below. Determine the change in gravitational potential energy of the lead shot in each trial. Note that the masses of lead shot should be converted to kilograms in this table.

Styrofoam Cup	Mass of the Lead Shot m (kg)	Acceleration Due to Gravity g (m/s^2)	Total Height the Lead Shot Falls h (m) (h = distance of one fall × the number of flips)	Change in Gravitational Potential Energy of the Lead Shot E_m (J) ($E_m = E_p = mgh$)
1		9.81		
2		9.81		

2. Complete a table in your notebook similar to the one below, determining the heat gained by the lead shot in each trial.

Styrofoam Cup	Mass of the Lead Shot m (g)	Temperature Change Δt (°C)	Specific Heat Capacity of Lead c (J/g°C)	Heat Gained by Lead Shot H (J) $H = mc\Delta t$
1			0.159	
2			0.159	

3. Construct a data table that includes the changes in gravitational potential energy of the lead shot and the heat gained by the lead shot for each trial. Using the data, draw a graph of heat gained by the lead shot as a function of the changes in the gravitational potential energy of the device. Draw the line of best fit through the data points.

4. Determine the slope of the line of best fit. What does this represent?

5. For each trial, determine the percent efficiency of the conversion of gravitational potential energy to heat. What is the average value of the percent efficiency of this device?

Forming Conclusions

6. Do your results support your hypothesis concerning the relationship between changes in mechanical energy and heat?

Applying and Connecting

7. Compare the percent efficiency of this device with the percent efficiency of other devices you have studied in this section. Is this device a good energy conversion device? Justify your answer.

Extending

8. The air in the tube is also heated as the tube is flipped. If this did not happen, would the percent efficiency be higher or lower? Explain.

9. Compare your results with those of other groups in your class. Determine what factors could have caused any difference in the percent efficiency values.

10. Suggest alterations to the design of the device that could improve the efficiency of the energy conversion.

reSEARCH

Many insulated coffee mugs on the market today are made from stainless steel, which is a good conductor of heat. This seems to be contrary to the designed function of an insulated coffee mug, which is to keep coffee hot by preventing the flow of heat. Use the library or the Internet to discover how stainless steel coffee mugs are designed to prevent the loss of heat. Draw a cross-sectional sketch of the mug, labelling all the parts, and their functions. Begin your search at

www.pearsoned.ca/school/science10

3. *Conversion of Total Thermal Energy to Useful Mechanical Energy or Vice Versa*

In many systems, the energy conversions involve thermal energy and mechanical energy. For example, the thermo-electric converter, or thermocouple, in Figure B3.8, page 204, converts thermal energy to mechanical energy to turn a fan. Not all the heat input is converted to mechanical energy in the process. Some of the heat is lost to the surroundings. To calculate the percent efficiency of this type of device that converts heat to mechanical energy, use the following equation:

$$\text{percent efficiency} = \frac{E_{\text{m (useful output)}}}{\text{heat}_{\text{total input}}} \times 100\%$$

For devices that convert mechanical energy to heat, use

$$\text{percent efficiency} = \frac{\text{heat}_{\text{useful output}}}{E_{\text{m (total input)}}} \times 100\%$$

In general, when you find the percent efficiency of any device, you are determining the percent of useful energy compared with the total energy input.

B3.3 Check and Reflect

Knowledge

1. In most machines, what type of energy is usually found as wasted energy?
2. Which component in the operation of a car consumes the most energy?
3. Explain what is meant by the term "efficiency," when applied to a machine.
4. What type of engine is the most efficient?

Applications

5. A machine consumes 1000 J of energy in doing 800 J of work in lifting a load.
   a) What is the energy input?
   b) What is the energy output?
   c) What value is classified as useful work?
   d) What value is classified as wasted energy?
   e) Calculate the percent efficiency of the machine.
6. Describe one situation where you would consider thermal energy as useful energy and one situation where you would consider thermal energy as wasted energy.
7. Calculate the percent efficiency of an engine that consumes 3.50×10^3 J of energy in doing 2.30×10^3 J of work.
8. The percent efficiency of a machine is 35.0%. What is the useful work done if the machine consumes 1.20×10^4 J of energy?
9. The percent efficiency of a machine is 35.0%. What is the input energy required if a 2.00×10^3-kg object is to be lifted 5.00 m?

Extensions

10. Suppose you wanted to determine the percent efficiency of your skateboard. What would you measure as the work input and what would you measure as the work output?
11. Compare a perpetual motion machine and an internal combustion engine in terms of percent efficiency.
12. Compare a perpetual motion machine and a Rube Goldberg machine in terms of percent efficiency.

B 3.4 Energy Applications

Two things about energy are certain: we cannot live without it and we cannot create it. We use it to heat homes, run machines, cook food, and power appliances, tools, and gadgets. Through all the centuries of discoveries by brilliant and inventive scientists and engineers, we have not found a way to create energy. The best we can do is control it or transform one form of energy into another. Where does all this energy come from?

info **BIT**

Earth receives about 1.75×10^{17} J of energy from the Sun every second. This amount of energy is more than the total energy consumed by humans since the beginning of civilization.

Energy Supply

Since the beginning of time, the most important and reliable source of energy on Earth has been the Sun (Figure B3.22). All primary energy sources are classified into two main categories: solar and non-solar energy sources.

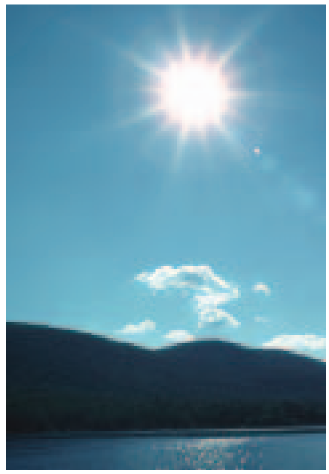


FIGURE B3.22 The Sun is the primary energy source for life on Earth.

Solar Energy Sources

Solar energy sources are those that are derived either directly or indirectly from the energy of the Sun. *Solar radiation* is the radiant energy from the Sun emitted by the hydrogen–hydrogen nuclear fusion reaction that occurs in the Sun's core. This radiant energy travels through space as electromagnetic radiation. It is captured directly by plants (through photosynthesis) or by Earth's surface, or by devices such as solar panels, solar cells, photovoltaic cells, and so on.

Wind energy is the result of heating of the surface of Earth by the Sun. This heating causes convection currents of air, or wind. The energy in the movement of air may be used to turn wind turbines. The kinetic energy of the turbine is converted into other forms of energy such as electrical energy.

Water energy results when surface water is heated by the Sun. It drives a hydrologic cycle. Heating causes evaporation of water into the atmosphere where it then condenses, creating rain. The falling rain creates flowing water in streams and rivers. This moving water can be converted into other forms of energy through hydro-electric dams.

Biomass is any form of organic matter, such as wood, wood residues, crop residues, seaweed, algae, and animal wastes. These substances are indirect solar energy sources, since they store energy from the Sun through the process of photosynthesis. All of these can be combusted to release chemical potential energy.

Fossil fuels such as oil, natural gas, and coal are also considered indirect solar energy sources because all fossil fuels were formed from plants and animals that lived millions of years ago.

Non-Solar Energy Sources

Non-solar energy sources have no relationship to the Sun. They include nuclear energy, which is the energy obtained from a conversion of mass to energy in a nuclear reaction. This reaction can be either *fission* (uranium or plutonium fission) or *fusion* (hydrogen–hydrogen fusion). Fission reactions can be controlled in a nuclear reactor, such as the CANDU reactor.

Geothermal energy is thermal energy from Earth's interior. Superheated

*info***BIT**

Biogas is the waste gas produced from decaying organic matter and contains up to 70% methane. At the Clover Bar landfill site in Edmonton, biogas is used to heat water to produce steam to operate a power station. This station produces enough electricity to meet the electrical needs of 10 000 homes per year.

water is evidence of the tremendous heat deep inside Earth. This water gushes to Earth's surface via geysers and hot springs, and it can be used to generate electricity. Geothermal power plants use the superheated water to create steam to power turbines. Geothermal energy can only be exploited in those areas with volcanic activity, where geysers and hot springs are found.

Tidal energy involves the movement of ocean water, creating tides. Tides are caused by the gravitational pull by the Moon and, to a lesser extent, by the Sun. The kinetic energy in this movement of water can be converted to other forms of energy, such as electricity. The tides in the Bay of Fundy are the highest in the world, reaching up to 17 m.

Renewable and Non-Renewable Energy Sources

Energy sources can also be further classified as **renewable energy sources** and **non-renewable energy sources**. Renewable energy sources are ones that are continually and infinitely available (solar, wind, water, geothermal, tidal, and biomass). Biomass is considered a renewable source of energy because forest reserves can be replaced in a reasonable length of time. Non-renewable energy sources are ones that are limited and irreplaceable (nuclear and fossil fuels).

Energy Sources and Electricity Generation

Although energy sources can be used directly, most of these energy sources are used to produce electrical energy, which is then used for a multitude of purposes. Electrical energy is one of the most important forms of energy in industrial societies. Before the 1900s, electricity was not widely used, but today it provides over 40% of all the energy consumed. Power-generating stations most commonly use fossil fuels, flowing water, wind, or nuclear energy as the initial energy sources, which are then converted into the mechanical energy used to rotate the turbines. Deciding which energy source to use when a power station is built depends on which source is the most readily available and practical in that area. For example, Pincher Creek in southern Alberta is very windy, which makes it an ideal location for wind turbines (Figure B3.23).

FIGURE B3.23 There are 60 wind turbines at the Castle River Wind Farm west of Pincher Creek in southern Alberta. Each turbine produces enough energy to power 300 homes a year.

Energy Demand

Historically, our ancestors used renewable sources of energy, such as solar energy and wood or biomass. Today, these sources make up only a small fraction of our energy supply. Our current consumption of energy from different sources is shown in Table B3.2.

TABLE B3.2 Global Yearly Energy Consumption from Different Sources (2001)

Energy Source	Global Yearly Energy Consumption ($\times 10^{18}$ J)
conventional oil	150*
coal	96
natural gas	92
hydro	25
nuclear	26

*includes shale oil and oil sands

Adapted from *BP Statistical Review of World Energy 2002*

infoBIT

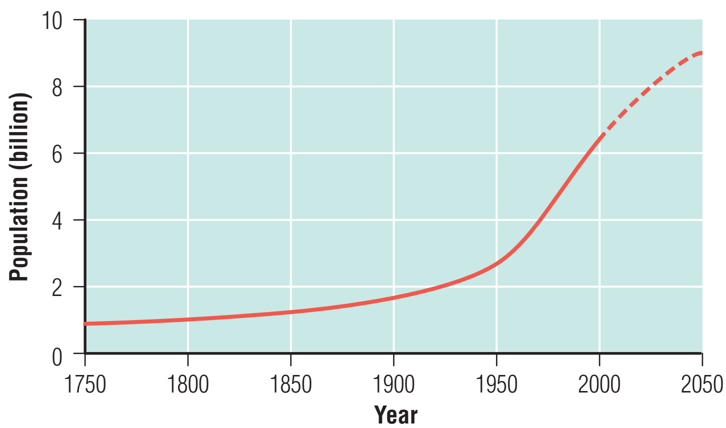
A recent discovery by two Alberta researchers is touted as the first new way of producing electricity in 160 years. Their electrokinetic microchannel battery harnesses the energy created on a tiny scale when a flowing liquid meets a solid surface. By squeezing water through a ceramic filter containing 10 000 microtubes, they were able to generate enough electricity to light a small bulb. This new way of producing electricity may one day replace hydrocarbon fuels as the source of energy for electrical generation.

Several factors have placed dangerous demands on our energy supplies. First, the amount of energy consumed per person has been increasing exponentially. Our ancestors consumed about 10 000 000 J or 10 MJ of energy per person per day. Today, the global average for energy consumption per person per day is 180 MJ. This figure rises for people in industrialized countries, who consume, on average, 1000 MJ per person per day!

Second, the world population is also growing exponentially. Up until the 1950s, the growth of the world's population was steady but slow. In the 1950s, there were huge innovations in medicine, such as the development of vaccines and antibiotics. Better public health increased the average life span. There were also technological innovations which improved people's lifestyles. As a result of all these developments, the world population has been increasing at an exponential rate (Figure B3.24). Currently, there are over 6 billion people on the planet. So, there are more people consuming more energy.

Third, many societies now use non-renewable energy sources rather than renewable sources as the primary source of energy. Until the 1950s in Alberta, most power stations produced electrical energy from hydro power, or flowing water. When large coal reserves were discovered near Edmonton, it then became cheaper to build coal-fired generating stations than hydro-electric dams. Today, only 5% of electricity generation in Alberta is from hydro power and 85% is from coal. The other 10% is from natural gas.

Global Population 1750–2002, with Projections to 2050



Adapted from United Nations *World Population Prospects, The 2002 Revision* and estimates by the Population Reference Bureau

FIGURE B3.24 The global population is predicted to reach 9.3 billion by 2050.

Activity B14

Decision-Making Investigation

Student Reference 4, 9, 11

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Comparing the Energy Content of Fossil Fuels Used in Alberta

Begin your search at www.pearsoned.ca/school/science10

The Issue

Which type of fossil fuels should be used in thermal energy plants in Alberta?

Background Information

Modern technological demands for readily available and relatively inexpensive energy sources have made fossil fuels the most widely used source of energy. Power stations use technologies that rely on fossil fuels as an initial source of energy. Alberta has reserves of all three fossil fuels, and they can be transported to all parts of the province. Coal is the most readily available, followed by oil, and then natural gas.

Suppose the Alberta government has proposed the construction of a power station in your area, and the station must use a fossil fuel as the initial source of energy. Your group has been asked to research which fossil fuel to use: oil, gas, or coal. The government will use the results of your research to make the most appropriate decision.

Analyze and Evaluate

1. Use the library or the Internet to do your research.
   a) Research the energy content of each type of fossil fuel in joules per kilogram of fuel (J/kg).
   b) Research the environmental effects of using each fossil fuel in your area.
   c) Research which source of energy will supply the most energy over the long term.
2. Analyze your research and decide which fossil fuel should be used.
3. Once your group has completed a written report recommending a particular fossil fuel, present the report to the rest of the class who will act as representatives of the government and the community. After the presentation, each member of your group must be able to justify and defend your recommendation.

FIGURE B3.25 (a) Oil is often transported in tankers. When tankers leak, spills can have lasting effects on ecosystems.

(b) Burning fossil fuels contributes to thermal pollution.

The Effects of Energy Use

Our dependence on fossil fuels has placed a strain on existing supplies. It has also had significant effects on the environment (Figure B3.25). The search for and extraction of fossil fuels have resulted in damage to ecosystems. For example, drilling for oil in the muskeg of northern Alberta has left scars on the landscape. There is also the danger of oil leaking from wells, polluting the surrounding area.

Even though fossil fuels are relatively cheap and convenient sources of energy, burning them may damage our environment permanently. Emissions from the combustion of fossil fuels contain greenhouse gases and oxides. Greenhouse gases contribute to climate change and oxides contribute to acid rain.

The overall effect of an increasing population, an increasing demand for energy, and the shift toward the exploitation of non-renewable energy sources is having far-reaching consequences.

Minds on... Hydro versus Coal-Burning Electricity Generation

Every time there is an energy conversion, some energy is wasted in the form of heat, as stated in the second law of thermodynamics. It has been determined that hydro-electric generating stations are 70% efficient and coal-burning stations are only 35% efficient. This means that twice as much energy is lost as heat in coal-burning power stations as in hydro-electric stations.

Study the diagrams of a hydro-electric power station and a coal-burning power station on page 192 and answer the following questions.

Questions

1. How many energy conversions take place in each type of generating station?
2. Identify all the locations where energy could be lost as heat.
3. Using your answers to the previous questions, explain why hydro-electric power stations are more efficient than coal-burning power stations.
4. Can you suggest how efficiency could be improved in each type of power station?

Energy Consumption and Conservation

Before the 1970s, the reserves of fossil fuels seemed inexhaustible. Because they were relatively simple to extract, fossil fuels were the most inexpensive and desirable sources of energy. In the 1970s, the major oil-producing nations severely cut back on oil production, which caused an oil shortage (Figure B3.26). The shortage, in turn, caused oil prices to skyrocket. The sudden shortage was called an energy crisis. This forced experts in industrialized nations to examine their consumption of oil and other fossil fuels. Experts realized that at the current rates of consumption, the reserves of the fossil fuels would soon be depleted. Because industrialized countries were greatly dependent on fossil fuels, efforts were made to research and develop alternative energy sources and technologies that could harness them.

FIGURE B3.26 The oil shortage in the 1970s resulted in long line-ups at gas stations.

At the current rate of consumption, our known fossil-fuel reserves are fast becoming depleted. Table B3.3 projects the number of years remaining for each fossil fuel as an energy source. Proven reserves are those that geological and engineering information indicates can be recovered in the future from known deposits under current economic and operating conditions.

TABLE B3.3 Comparison of Three Fossil Fuels

Fossil Fuel	Global Yearly Consumption of the Fossil Fuel as of 2001 ($\times 10^{18}$ J)	Proven Reserves of the Fossil Fuel as of 2001 ($\times 10^{18}$ J)	Projected Number of Years Left (assuming 2001 demands)
conventional oil	150*	6 088†	40†
coal	96	21 362	216
natural gas	92	5 893	62

*includes shale oil and oil sands †does not include shale oil and oil sands

Adapted from *BP Statistical Review of World Energy 2002*

If everyone reduced their consumption of fossil fuels by 25%, this would extend reserves for several more years. An alternative is to search for new fossil fuel reserves around the world. However, these two approaches are only short-term solutions because they are merely prolonging the inevitable.